TEMPERATURE CONTROL OF STIRRED TANK HEATER USING ON-LINE COMPUTER

A Thesis Submitted

In Partial Fulfilment of the Requirements

For the Degree of

MASTER OF TECHNOLOGY IN ELECTRICAL ENGINEERING

by

PRAHLAD KUMAR SRIVASTAVA

to the

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CERTIFICATE

This is to certify that the work on "Temperature Control of Stirred Tank Heater Using On-Line Computer" by Mr. Prahlad Kumar Srivastava has been carried out under my supervision and this has not been submitted elsewhere for a degree.

H.N. Mahabala
Dr. H.N. Mahabala
Associate Professor and Head
Computer Centre
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

EE-1972-M-SRI-TEM

to
my
mother

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Outgoing and indefatigueable customer engineers, of IBM-India, Mr N. Saxena and Mr R.D. Hinduja have rendered a great deal of help to me in studying the IBM 1800 system. Their friendly association through the project enriches my experience academic as well as human.

An interdisciplinary project like this could not have been completed without the assistance, concrete in nature, of P.V.H.M.L. Narasimham and N.S. Wani. As any one who has worked on a project long enough knows, the encouragement and assistance the friends give are very valuable and the help given by R.K. 'Malik and R.K. Gupta will particularly be remebered with gratitude.

Successful completion of the project is due to the assitance of the staff of Departments of Electrical Engineering and Chemical Engineering, which I thankfully acknowledge.

– Prahlad Kumar Srivastava

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LIST OF ABBREVIATIONS

C	Specific heat of liquid
ε	Error
ρ	Density of liquid
K_c	Controller constant
m	First order coefficient of controller
n	Zero order coefficient of controller
q	Heat input per ~~k~~minute
q_s	Heat required to maintain set point temperature
R_f	Feed back resistance
R_{in}	Input resistance
T_i	Input stream temperature
T_R	Set point temperature
T_m	Measured temperature
T_{is}	Steady state temperature of input stream
T_s	Steady state temperature of tank
T	Tank temperature
T_i'	Deviation in input stream temperature
T'	Deviation in tank temperature
τ_p	Process time constant
τ_m	Measuring Element time constant
τ_I	Integral time constant of controller
τ_D	Differential time constant of controller
v	Voltage (reference) from A.D.A. output
ADA	Analog Driver Amplifier

IC	Integrated circuit
ILSW	Interrupt device status word
INT	Interrupt
LWA	Level word area
MIC	Master interrupt control
NSI	Next sequential instruction
PSC	Program sequence control
PISW	Process Interrupt status word
TIBA	Table of interrupt branch address

ABSTRACT

The contents of this thesis presents the work done to interface the "stirred tank heater" to IBM 1800 for the control of tank temperature. This represents a part of the work towards the use of digital computer for process control. Variable gain differential amplifier and 'Power Control Units' are designed for this purpose. The programs are written to service the interrupt, from process terminals, process data acquisition and control. Proportional integral control scheme has been used in the program which operates in time shared mode.

CHAPTER 1

INTRODUCTION

The digital computers have been successfully employed as data processing aids in business and management for a long time. The design of computer, which will be useful for control of industrial processes and other Real-Time applications was suggested nearly a decade ago. Enough experimentation was done to develop capability of computer to operate in "Real-Time" and with the speed and accuracy to control critical processes safely.

Experience has shown that the use of computer as a tool for process-control has the potential to increase process output, raise efficiency, improve quality and cut operating cost.

IBM 1800 is a computer designed for process-control and other real-time applications, such as data logging, air-line reservation system, air-craft and missile control etc. It is a third generation computer, employing solid-state technology. The system is compatable to IBM 360.

Classical control methods make use of analog controllers for controlling parameters of a physical process. The recent developments have led to advanced control system of following types.[15]

1. Closed Loop Supervisory Control: It keeps track of "set point*". It issues commands to operator to take necessary action.
2. Direct Digital Control: The computer itself provides analog backup to keep track of set point by itself. DDC is becoming increasingly attractive to analog control these days.

1.1 PROBLEM SPECIFICATION

The problem is to control the temperature in a 'Stirred Tank Heater' using Direct Digital Control technique. IBM 1800 is used for this job. The transducer attached to the process converts temperature to an electrical signal. The electrical signals obtained are converted to digital form using Analog to Digital Converter provided with the system.

The difference between the set point and measured value of temperature is an error signal. The error signal is an input to the control program. The computer

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* Set Point: It is the desired value of certain process parameter. In the present experiment, it is the required temperature of the tank.

calculates the required current or voltage to be applied to the heater which in turn lowers or increases the temperature of the tank as desired to maintain the temperature of the tank nearly constant. The variation allowed depend on the sensitivity of the transducer used to sense temperature and the accuracy of A to D conversion.

1.2 PROGRAMMING SYSTEM USED[1,16]

The programming system used for this application is "Time Sharing Executive System". A brief description of this system is given below.

This system divides the memory into two parts.

1. Executive: It contains all the required system programs and few important programs of the user which have to be executed on the priority basis.
2. Variable Core: This area is available for the processing of process * and non-process ** job.

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* Process Job: These are the type of jobs, which require computer attention in 'Real-Time' and are run at definite intervals of time. These jobs in general get the priority over non-process job for execution.

** Non-process Job : These are some application programs like pay-roll computation and other data processing work which done when process program is not under execution.

Whenever some process program is being executed, and an interrupt arrives from the process, non-process program is saved in non-process save area (defined on the disk) and process job is brought into execution. When an interrupt arrives while processing a process job, it is recorded and queued depending on its priority. On the completion of process program in execution, next process job waiting at the top of queue is brought into execution. If no process job is available non-process program is executed.

The advantage of TSX[16] system is that the tailored system provides the time sharing facility and the Executive occupies relatively smaller amount of core (than MPX).[17]

CHAPTER 2

CONTROL SCHEME

2.1 BASIC METHODS OF TEMPERATURE CONTROL[2]

There are, in general, three methods to control the temperature of masses.

1. The thermal resistance between a heat source and a heat sink is controlled; the control can be accomplished by either a permanent or time varying change for any combination of conduction, convection, or radiation heat transfer.
2. The heat dissipation at a controlled mass or on a thermal path between the controlled mass and its heat sink is regulated, either by a permanent change or in a contineously or discretely varying way.
3. The heat absorption capacity of heat sink is controlled.

2.2 PHYSICAL LAYOUT OF THE SYSTEM

The experiment being a demonstration set-up for the control of the process parameter, a simple scheme is selected.

The present experiment demonstrates the control of temperature in a stirred tank.

The second approach, described in Section 2.1 is utilized to control the temperature in a "stirred tank heater".

Figure 2.1.1 represents sketch of the apparatus. Water stream at room temperature T_i enters on well stirred tank at a constant flow rate w. The heated water leaves the tank at the same flow rate. It is desired to maintain the temperature in the tank at T_R by means of controller. If the indicated tank temperature T_m differs from the desired temperature T_R the controller senses the difference or error, $\varepsilon = T_R - T_m$ and changes the heat input in such a way as to reduce the magnitude of ε. The heat is supplied to the tank, by dipping an immersion heater in the tank. The flow of electrical power to the heater is regulated by a control unit, which regulates the current to a resistance heating element.

To maintain a constant flow and discharge to and from the tank, pumps have been used in input and output lines. To regulate the flow the valves are

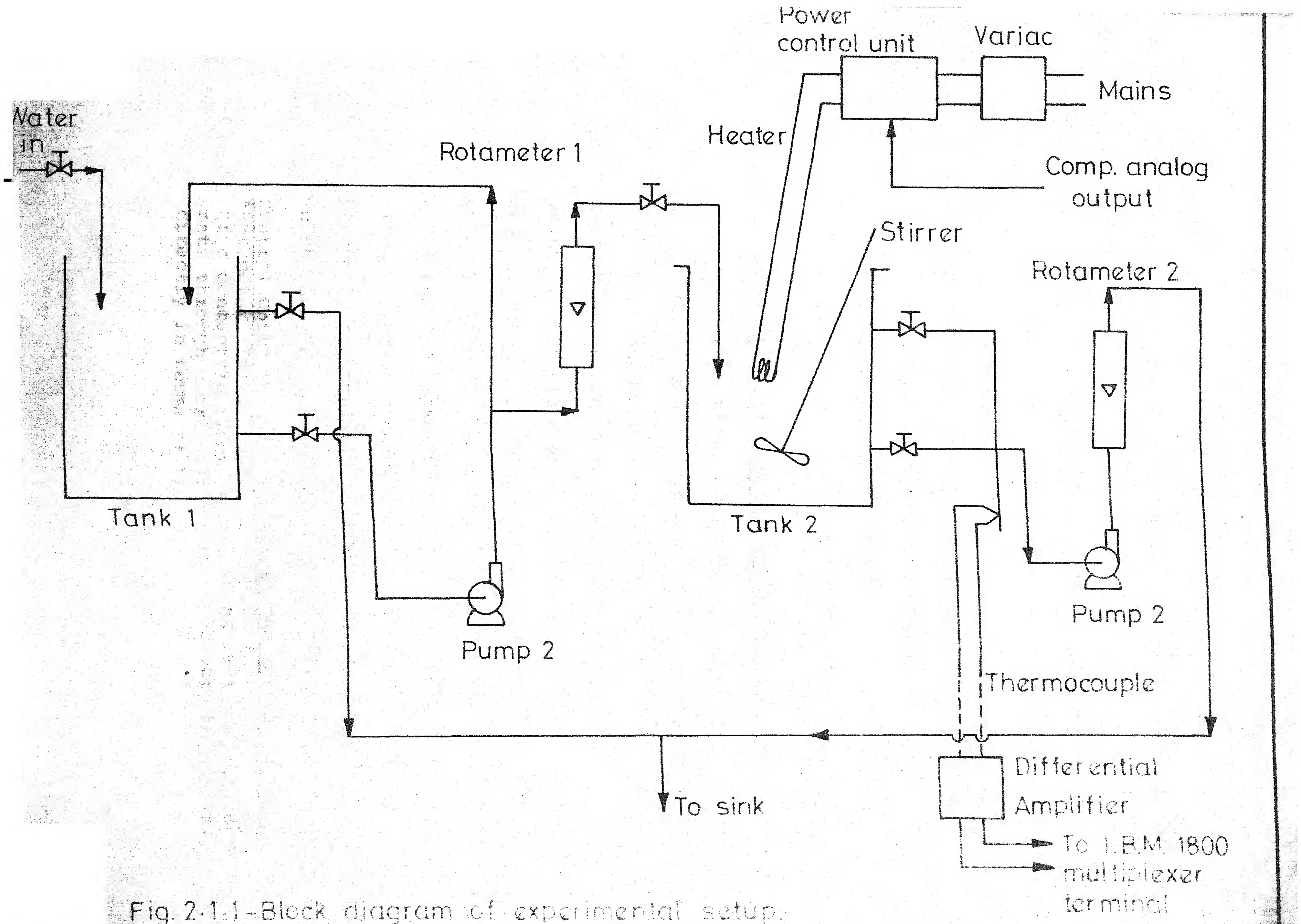

Fig. 2-1-1-Block diagram of experimental setup.

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provided in the input and output lines. The Rotameters* attached in the lines indicate the flow in u.s. gallons/minute.

2.2.1 Components of the control system:

The system shown in Figure 2.11 is divided into following components.

1. Process (stirred tank heater).
2. Measuring Element (Thermocouple)
3. ON-LINE Computer (IBM 1800)
4. Final Control Element (Thyristor controlled Power Control Unit)

2.2.2 Control loop representation in blocks

For computational purposes, it is convenient to represent the control system of Figure 2.11 by means of block diagram shown in Figure 2.2.2. The control system is a closed loop system because the measured value of controlled variable (temperature) is fed to computer. This value in-turn is read and compared with set point value. If there is any difference between measured value and set point value, an error signal is generated. This error is used as a parameter to simulated controller in the computer, which gives analog output which is utilized by "Power Control Unit" to control power to the system in such

*Rotameter: It is a variable area flowmeter. The edge of a concentric float, serves as an indicator of flow rate through a pre-caliberated scale attached to it, directly in terms of flow units.

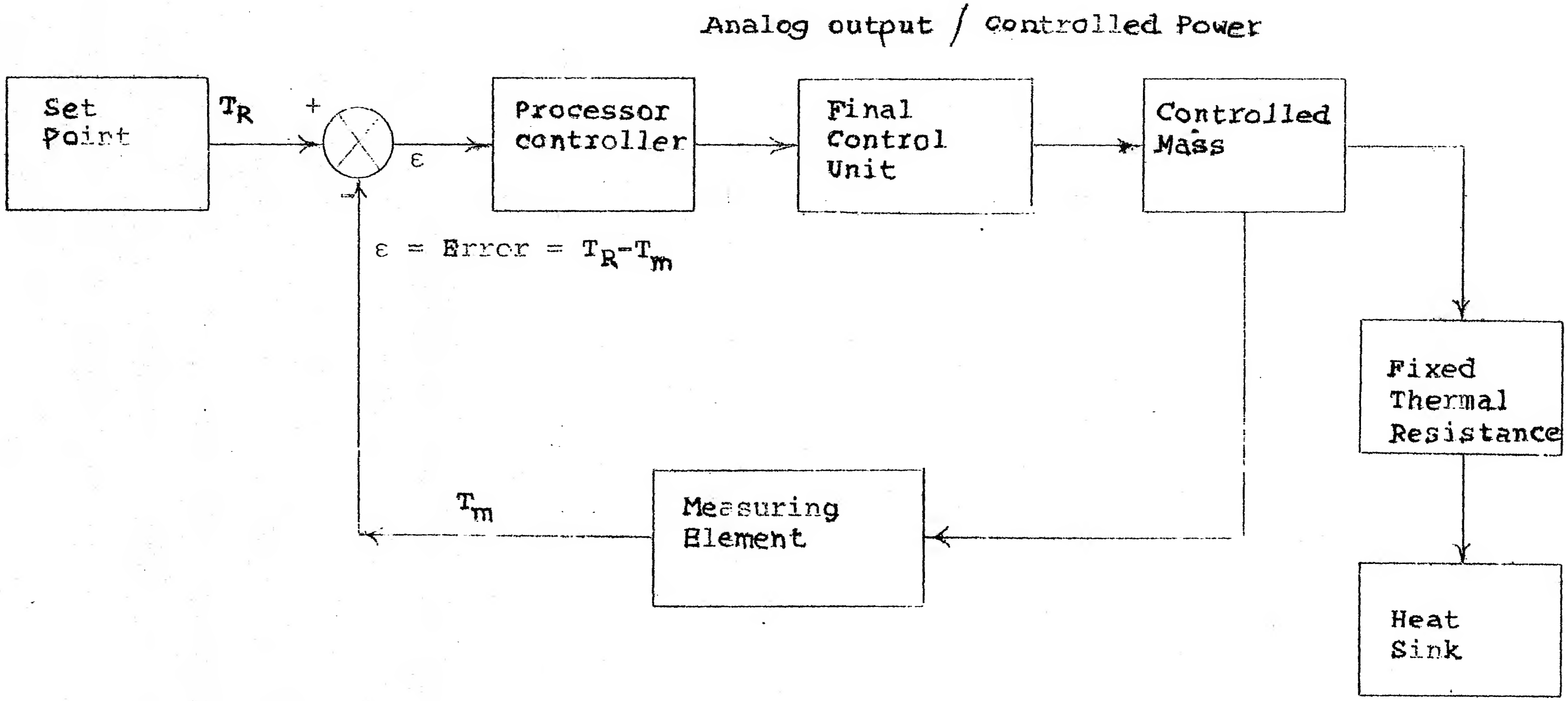

FIG. 2.2.2 Block Diagram of Control System.

a way as to return the controlled variable to set point.

2.2.3 Mathematical Model of the System[3]

The mathematical model of the system is built to calculate the response of the system. The overall transfer function of the control loop is determined to find out the stability of the system. It also helps to find out the coefficients of general control equation for optimal control.

The effect of sampling in DDC is to produce an steady state error. It also superimposes noise on the signal. The sampling speed has to be adjusted such that the noise introduced is minimum and at the same time the deviation from 'set point' is also reduced.

To calculate the overall transfer function of the process, the transfer functions of individual blocks are to be calculated.

2.2.4 Transfer Function of the Process

To calculate the transfer function of the process following assumptions are made

1. Water flow in the input and output lines are constant and adjusted to be equal.
2. Flow rate of heat 'q' is instantanously available and independent of temperature in the tank.

3. The radiation losses have been neglected.

Applying unsteady state energy balance in the heating tank gives

$$q + W.C.(T_i - T_o) - W.C.(T - T_o) = \rho.C.V.\frac{dT}{dt} \qquad (1)$$

where

q is heat added instantaneously

w is flow rate (mass/time)

T_i is input water temperature

T is output water temperature

T_o is reference temperature

ρ is density of liquid

V is volume of liquid in the tank.

at steady state, $\frac{dT}{dt}$ is zero, so equation (1) can be written as

$$q_s + WC\,(T_{i_s} - T_o) - WC\,(T_s - T_o) = 0 \qquad (2)$$

affix 's' represent steady state value of these parameters.

Subtracting (2) from (1) we get

$$(q-q_s) + WC[(T_i-T_{i_s}) - (T-T_s)] = \rho CV\frac{d}{dt}(T-T_s) \qquad (3)$$

introducing deviation variables

$$Q = q - q_s \qquad (4)$$

$$T_i' = T_i - T_{i_s} \qquad (5)$$

$$T' = T - T_s \qquad (6)$$

$$Q + WC\,(T_i' - T') = \rho CV\frac{dT'}{dt} \tag{7}$$

Taking laplace transform

$$Q(s) + WC[T_i'(s) - T'(s)] = \rho CV\ sT'(s) \tag{8}$$

or

$$T'(s)\ [1 + \frac{\rho V}{W}.s] = \frac{Q(s)}{WC} + T_i'(s) \tag{9}$$

or

$$T'(s) = \frac{(\frac{1}{WC})}{1+\tau_p.s}\,Q(s) + \frac{1}{1+\tau_p.s}\,T_i'(s) \tag{10}$$

where

$$\tau_p = \frac{\rho V}{W} = \text{time constant of process.}$$

Assuming that input water temperature to the tank remains constant for all practical purposes. This means $T_i'(t) = 0$, hence transfer function can be written as

$$\frac{T'(s)}{Q\ (s)} = \frac{(1/WC)}{1+\tau.s}$$

where

$$\tau_p = \frac{\rho V}{W}.$$

2.2.5 <u>Measuring Element:</u>

Thermocouple is selected as temperature measuring device. The thermocouple which senses the tank temperature T and transmits signal T_m to the computer, exhibits some dynamic lag. The dynamic lag is observed to be the first order. The transfer function of first order system is equal to

$$\frac{T_m'(s)}{T'(s)} = \frac{1}{\tau_m . s+1} \tag{11}$$

where

$Tm' = T_m - T_{ms}$ and $T' = T - T_s$ (parameters with suffix 's' represent steady state values).

Since the time constant of thermocouple is much smaller than the time constant of the process to we can neglect it. Thus the transfer function reduces to

$$G_m = \frac{T_m'(s)}{T'(s)} = 1 \tag{12}$$

2.2.6 Controller and Final Control Element[4]

For convenience the blocks representing the controller and final control element have been combined into one block. The relationship for a proportional controller is

$$q = K_c \cdot \varepsilon + \frac{K_c}{\tau_I} \int_0^t \varepsilon \, dt + K_c \cdot \tau_D \frac{d\varepsilon}{dt} + q_s \tag{13}$$

for P.I.D. Control

$$\frac{Q(s)}{\varepsilon(s)} = K_c \left(1 + \tau_D . s + \frac{1}{\tau_I . s}\right) \tag{13A}$$

Some work has been done in DDC area. Following are the conclusions of the work.

1. Proportional action can not be used in direct digital control as it results in random walk of controlled variable (Temperature) about the set point.
2. At least two term control should be used, e.g., Proportional Integral Control.
3. The derivative term does not improve the performance. Bernard[4] states that derivative term has damping effect as sampling interval is increased.

So far our purpose, proportional integral control is used. The transfer function of controller is

$$G_c = \frac{Q(s)}{\varepsilon(s)} = K_c \left(1 + \frac{1}{\tau_I \cdot s}\right). \tag{13c}$$

Control Algorithm

General equation for PI control is

$$Q = q_s + K_c \left[\varepsilon + \frac{1}{\tau_s} \int \varepsilon \, dt\right]$$

where

q_s = heat supplied at steady state

τ_I = integral time constant

K_c = proportional time constant

ε = error

Q = heat to be supplied

Expressing the above equation in difference equation form[5]

$$Q_n = q_s + K_c \left[E_n + \frac{\tau}{\tau_I} \Sigma E_n\right] \qquad (14)$$

τ = sampling period

E_n = Current error

Q_n = Currently amount of heat supplied to minimize error.

Suppose we always supply heat required to maintain steady state. For fluctuations in process, we want to determine heat change required to control the process.

$$\Delta Q_n = Q_n - Q_{n-1}$$

$$\Delta Q_n = K_c \left[(E_n - E_{n-1}) + \frac{\tau}{\tau_I} E_n\right] \qquad (15)$$

Hence the total amount of heat Q_n given to tank after nth sampling

$$Q_n = Q_{n-1} + \Delta Q_n \qquad (16)$$

to compensate for the deviation occurred between (n-1)th and nth sampling period.

The control loop is finally represented as shown in Figure 2.2.3.

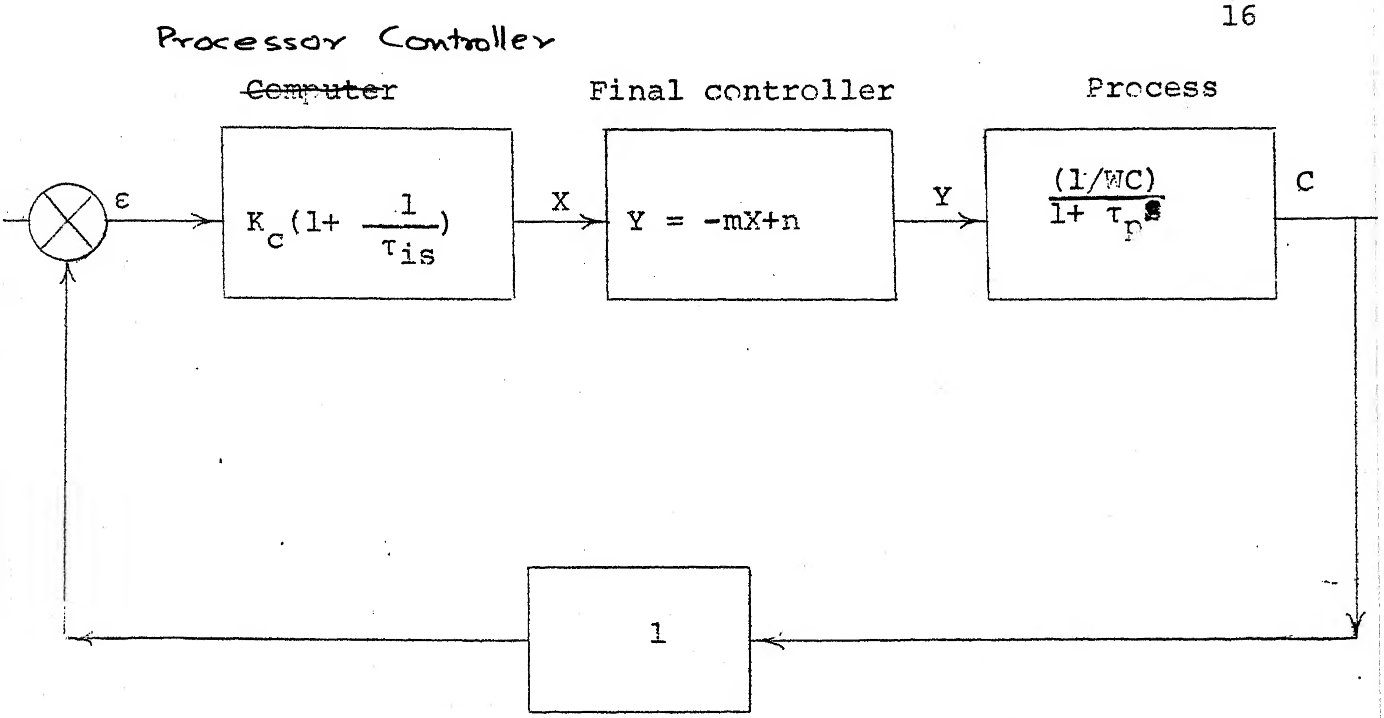

FIG. 2.2.3 : Final representation of control loop.

2.2.7 <u>Determination of Criterion for Optimal Control:</u>

The value of various constants in control equation are determined, such that error is minimized. The criteria for for optimal control can be mathematically represented by

$$I = \int_{-\infty}^{\infty} \varepsilon^2 \, dt \quad \text{is minimum.}$$

The error is represented by

$$\varepsilon = R - C$$

The controlled variable C is mathematically represented by,

$$C = [-m\{\varepsilon.K_c(1 + \frac{1}{\tau_i.S})\} + n]\ \frac{\frac{1}{W.C}}{\tau_p.S+1}$$

Thus,

$$\varepsilon = R - [-m\{\varepsilon.K_c\ (1 + \frac{1}{\tau_i.S})\} + n]\ \frac{\frac{1}{W.C}}{\tau_p.S+1}$$

$$\varepsilon = R + \varepsilon.m.K_c\ (1 + \frac{1}{\tau_i.S})\ \frac{\frac{1}{W.C}}{\tau_p.S+1} - n\ \frac{\frac{1}{W.C}}{\tau_p.S+1}$$

$$\varepsilon = \frac{R - n\ .\ \frac{\frac{1}{W.C}}{\tau_p.S+1}}{1-m.K_c(1 + \frac{1}{\tau_i.S})\ \frac{\frac{1}{W.C}}{\tau_p.S+1}}$$

$$\varepsilon = \frac{R.W.C.\ \tau_i.S.\ (\tau_p.S+1) - n}{W.C.\tau_i S^2 + T_i.S\ (W.C - m.K_c) - m.K_c}$$

If we give a step to the system, then

$$R = 1/S$$

So,

$$\varepsilon = \frac{W.C.\ \tau_i\ (\tau_p.S+1) - n}{W.C.\ \tau_i.S^2 + \tau_i.S\ (W.C. - m.K_c) - m.K_c}$$

$$= \frac{W.C.\ \tau_i.\tau_p.S + (W.C.\ \tau_i - n)}{W.C.\tau_i.\tau_p.S^2 + \tau_i.S(W.C.-m.K_c) - m\ K_c}$$

The integral square error is represented as,

$$I = \int_{-\infty}^{\infty} \varepsilon^2.dt = \int_{-\infty}^{\infty} \varepsilon.\ \varepsilon\ dt$$

This is represented in frequency plane as

$$I = \frac{1}{2\pi j} \int_{-\infty}^{\infty} \varepsilon(S).\ \varepsilon(-S).dS.$$

The solution to this problem has been worked out and is of the form:

$$I = \frac{C_1^{\,2}\, d_o + C_o^{\,2} d_2}{2d_o\, d_1\, d_2}$$

For our problem

$$C_o = W.C.\ \tau_i . \tau_p$$

$$C_1 = (W.C.\ \tau_i - n)$$

$$d_o = W.C.\ \tau_i . \tau_p$$

$$d_1 = (W.C. - m\, K_c).\ \tau_i$$

$$d_2 = -m\, K_c$$

$$I = \frac{(W.C\,\tau_i - n)^2\, \tau_p\, W.C.\tau_i + (W.C.\tau_i.\tau_p)^2\ (-m\, K_c)}{2\, W.C.\ \tau_i^{\,2}.\tau_p\,(W.C.-m.K_c)\,(-m\, K_c)}$$

$$= \frac{(W.C\ \tau_i - n)^2}{2\tau_i\ (W.C - m\, K_c)\ (-m\, K_c)} + \frac{\tau_p}{2(W.C - m.K_c)}$$

$$= \frac{W^2C^2\, \tau_i^{\,2}}{2\,(W.C - m.K_c)\,(-m.K_c)} - \frac{n.W.C}{\tau_p\ (W.C-mK_c)\,(-mK_c)}$$

$$+ \frac{n^2}{2\tau_i\ (W.C - m\, K_c)\,(-m\, K_c)} + \frac{\tau_p}{2\ (W.C - m.K_c)}$$

The value of K_c and τ_i is determined from minimum error considerations from following considerations

$$\frac{\partial I}{\partial K_c} = 0 \qquad (1)$$

$$\frac{\partial I}{\partial \tau_i} = 0 \qquad (2)$$

CONDITION 1: From equation (1)

$$- \frac{W.C\,\tau_i}{2\tau_p} \left[\frac{1}{(W.C-m\,K_c)(-m\,K_c)} \right]^2 -m(-m\,K_c) + -m\,(-m\,K_c)$$

$$- \frac{n\,W.C}{\tau_p} \left[\frac{1}{(W.C - m\,K_c)(-m\,K_c)} \right]^2 \{+\,2m\,K_c\}$$

$$+ \frac{n^2}{2\tau_i\,\tau_p} \left[\frac{-1}{(W.C-m\,K_c)(-m\,K_c)} \right]^2 \{2\,m\,K_c\}$$

$$+ \frac{\tau_p}{2} \left[\frac{1}{(W.C-m\,K_c)} \right]^2 (-\,m\,K_c)$$

$$\frac{1}{(W.C-m\,K_c)^2} \left[- \frac{W.C\tau_i}{\tau_p.m\,K_c} - \frac{2n.W.C}{\tau_p.\,m\,K_c} - \frac{n^2}{\tau_i.\tau_p\,m\,K_c} \quad \frac{m.K_c\,\tau_p}{2} \right] =$$

For this consideration

$$K_c = \infty$$

We select K_c = 1000 onwards for practical purposes

CONDITION II: From equation (2)

It gives

$$W^2C^2\tau_i = \frac{n^2}{2\,\tau_i^{\,2}}$$

$$\tau_i^{\,3} = \frac{n^2}{2W^2C^2}$$

$$\tau_i = \frac{1}{3}\sqrt{\frac{n^2}{2\,W^2C^2}} = \frac{1}{3}\sqrt{\frac{n^2}{2W^2}}$$

The above values of K_c and τ_i are used in the control routine.

2.4 SOFTWARE ASPECTS OF THE SCHEME:

The idea of the ON-LINE control is that periodically, the program to measure temperature and control it should be executed. The time interval at which the program is to be executed is set by the "count" routine so that at set time interval, the programmed interrupt occurs and the program is loaded into memory. This operation is initiated by the process interrupt (PISW bit 03).

The control program "CNTRL" have been stored as a subroutine on the disk. For this routine the response time is not a critical problem. The program PMESS is an interrupt servicing core load and permanantly resides on disk. The subroutine"INT 1" which calls "PMESS" core load is built in as a part of executive. As the interrupt arrives, this routine is immediately serviced.

2.4.1: Initiation of Program Execution:

The program is initiated by the process interrupt at PISW (group 00, bit 03) when the interrupt occurs in the system, the source of interrupt is determined by the Executive. If the source of interrupt is found to be process interrupt bit 03, the SUBROUTINE 'INT 1' included in the executive services the interrupt. At the completion of the interrupt service, following action will be

taken depending on the status of the system.

1. The interrupting program is queued depending on its priority of a process job is currently under execution. At the completion of this job, the core load waiting at the top of the queue at this time is loaded onto memory.

2. If a nonprocess job is in execution, the job in execution is saved onto disk in interrupt save area and the main line program PMESS which is stored in the disk in core image form is loaded in the core memory.

The main line program ANLOG as it is executed performs the following steps sequentially.

1. Asks for "Set point" temperature value? This value is supplied through key-board (1816) input.

2. Asks for ambient temperature. It is supplied through key board input.

3. Depending on set point temperature and ambient temperature and max. capacity of heater max. flow rate allowed is calculated and operater is asked to adjust the flow rate less than max. flow rate. Operater adjusts the flow rate and feeds the value of adjusted flow rate to computer through key board and calls program ANLOG.

4. It reads the analog voltage at multiplexer point 01 and its value is stored in some area. The binary value in A.D.C. register is converted to the exact voltage value.

5. With the help of 'Calibration Curve' of thermocouple, the analog voltage read is converted to its equivalent temperature value.

6. The difference between the 'Set-Point' temperature and measured temperature gives the error signal.

7. Now the main line program 'ANLOG' calls the subroutine 'CNTRL' control which calculates the output value depending on the magnitude of error signal.

8. The digital output obtained from the above step is converted to equivalent analog voltage using a D/A converter. This conversion is achieved by the routine 'OUTPT' which makes use of system routine 'DAOP'.

9. The main routine ANLOG is executed after specified interval, so that a corrective action is taken before a major deviation of temperature occurs from its 'Set Point' value. This is achieved by the 'COUNT' routine included in the executive.

CHAPTER 3

HARDWARE DEVELOPMENT

3.1 MEASUREMENT OF TEMPERATURE [6,7,8]

Thermocouple* is used for the measurement of temperature of the tank. The hot junction is kept in the tank, where the temperature is to be measured. The electro-motive-force (e.m.f.) generated by the temperature change at the hot junction of the thermo-couple is measured with respect to the reference junction (cold) which is kept in cold water. This e.m.f. is transmitted to computer multiplexer terminals after suitable amplification.

Following points are considered for the choice of thermocouple.

1. Linearity in range of operation.
2. Higher e.m.f. per degree change in temperature, for higher accuracy in measurement.
3. Higher e.m.f. developed in the temperature range of operation. It reduces the complexities in signal transmission and amplifier design.

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*-A device that consists of junction of two dissimiler metallic conductors in which an e.m.f. is induced, when the conductors are maintained at different temperature.

The choice for thermocouple goes because of their small size, simple construction, ruggedness and linearity.

Base metal thermocouple (Iron Constantan - Type J) is chosen for the temperature measurement in the experimental set up. Amongst all types of thermocouple available, the above mentioned serves the purpose best.

3.12 COLD JUNCTION

The cold junction is kept in water (at room temperature). Since the set up has been fixed in an air-conditioned room, the temperature variations of the cold junction is quite low and the arrangement provide only moderate accuracy.

If this set up is at the place where ambient temperature variations, which effect temperature of reference junction are very frequent a temperature compensating network is required.

3.13 E.M.F. MEASUREMENT

The thermocouple output is suitably amplified by properly selecting the gain setting of amplifier and is transmitted to multiplexer (Relay type) and of computer. There the signal is converted to digital form using an analog to digital converter. The converted

digital values are read by computer into the accumulator.

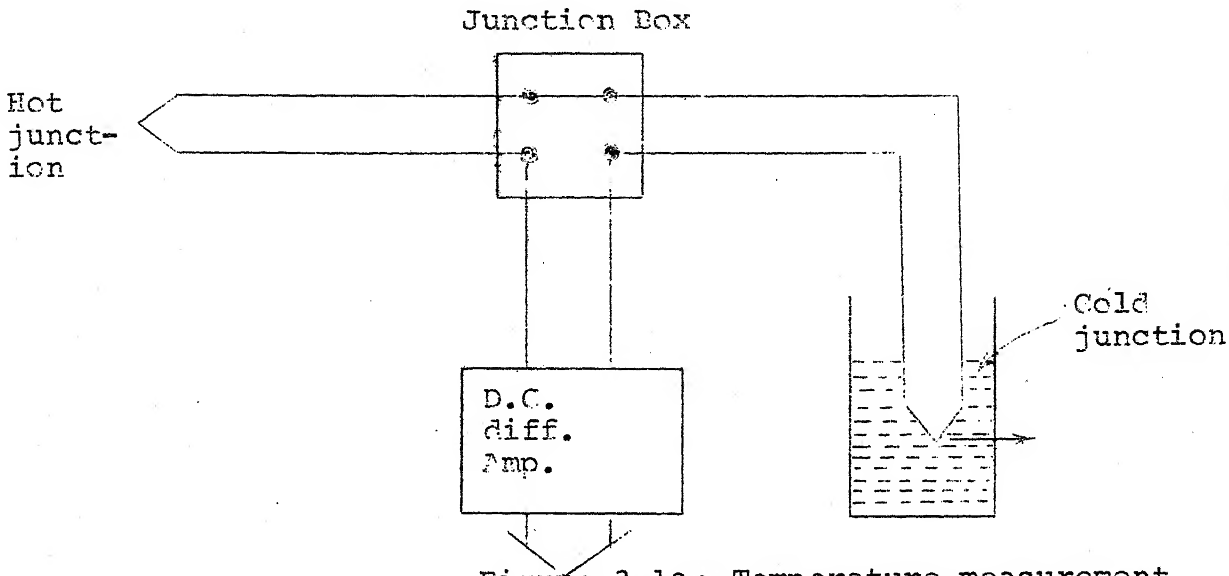


Figure 3.13: Temperature measurement using thermocouple

3.14 SIGNAL NOISE

In general the size of the process necessitates connexion of transducer by long cables to the input unit of computer. Quite often connecting cable is run close to the source of mains voltage, resulting in pickup on the leads. This pick-up voltage is added to the transducer output. For chemical processes, the frequency of information signal is much small compared to the pick-up frequency. Thus by designing a suitable low pass RC filter, between connecting cable and multiplexer, pick-up can be attenuated sufficiently.

In the experimental set-up, thermocouple is used to measure temperature. In the range 0-100°C, which developes a voltage of the order of 3m volts while wo working with the singal level of this order, electrical noise is a real problem. Appendix I presents a note on 'NOISE IN INSTRUMENT CIRCUIT'. A shielding procedure as shown in Figure 3.14 is used which reduces noise to a considerable limit.

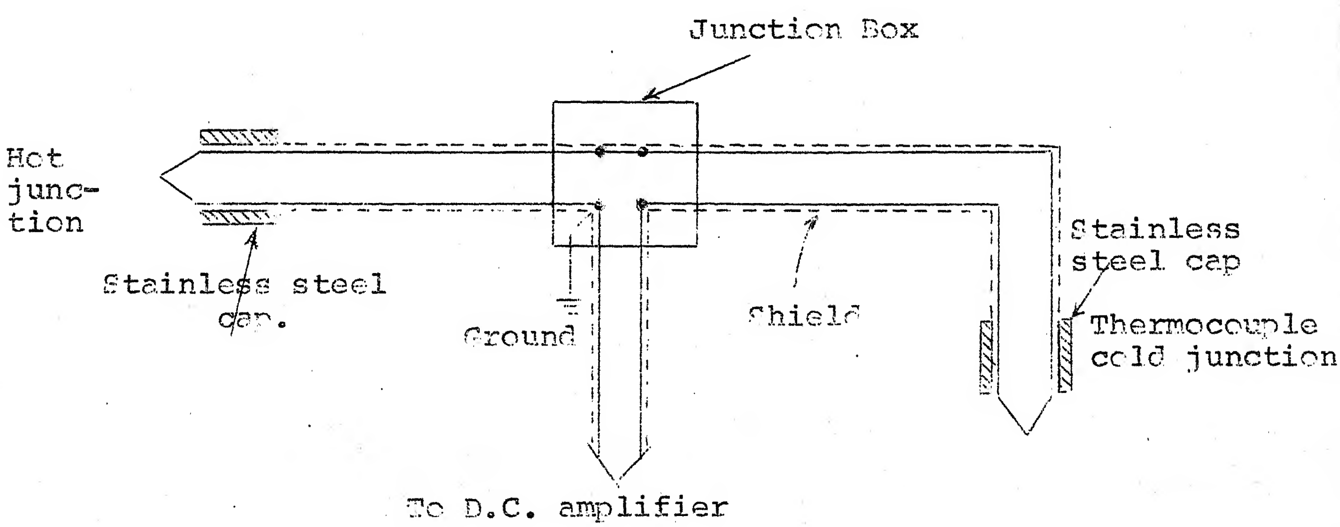


Fig. 3.1.4: Shielding procedure of thermocouple.

3.2 SIGNAL TRANSMISSION[9]

From the process, the type of signals available is usually d.c. in nature. These signals can be transmitted over moderately large distances. One thousand feet is considered nominal maximum. In any case source must have the capability to drive the total loop impedance, which is the sum of cable impedance and input impedance and input impedance of receiver (Only at low frequencies).

High level d.c. signals are transmitted directly on signal cables. The shielded cable is normally used to avoid noise pick up.

Following factors were considered for the transmission of high level signal.

A. 1. Ratio of receiver input impedance to source output impedance is kept greater than 1000, The diff. amplifier output (output impedance 750 Ω) is connected to relay multiplexer (input impedance 10 M Ω). So the above condition is satisfied.

2. Transmission Distance and Resulting Cable Impedance: The cable impedance is added to source to find the overall source impedance. In present experimental set-up, the input

signal cable is approximately 20 feet in length. So the cable impedance (less than 5 Ω) is negligible compared to source (750 Ω). Condition 1 is satisfied considering the overall source impedance.

B. The cable resistance and capacitance combines together to form a RC network, which acts like a filter. This filter should have a cut off frequency higher than the highest significant frequency in the signal input, so that the signals reach the computer without being seriously distorted and noise is reduced.

For the transmission of low level signals, following points are very helpful.

1. Transmission distance is kept as short as possible.
2. Signal cable shield is tied to the low side of the common point of signal source (the shield starts, right after the junction of thermocouple) and is maintained continuous upto computer multiplexer (Relay) terminals.
3. It is ensured that neither the cable shield nor the signal ground is grounded at more than one point.
4. All the power lines etc. are kept away from signal lines, so as to minimise the stray pick-up. If it becomes necessary to cross signal lines and power lines, they should be cut at right angle.

Typical specifications of cable recommended for the analog signals transmission to computer are the following.

1. Wire size should be #16 or # 18 A.W.G. to allow easy handling and termination without sacrificing strength or workability. This minimizes the lead resistance in the transmission line. Stranded wire with 19 strands is recommended.
2. The cable should be twisted pair, shielded and insulated. If multi pair cable is used, an overall shield and insulation is recommended in addition to pair shield and insulation.
3. Insulation should be rated to a minimum of 600 volts.
4. The temperature rating of cables must be consistent with maximum possible temperature conditions. (Recommended minimum specification is 75°C).

The signals of following types are generated in the process and in the computer. They are transmitted using different type of cables:

1. Thermocouple signal transmission to differential amplifier: Twisted pair, shield with braided copper.
2. Differential Amplifier to Computer: Two core, insulated and shielded.

3. Computer analog output to Power Control Unit:

Single core shielded and insulated.

3.3 INPUT INTERFACE:

As discussed earlier, thermocouples are used for the measurement of temperature. The magnitude of thermocouple voltages are very small (of the order microvolts /°C). Since the input to computer must be of the order of volts (1-5 volts) high gain differential amplifier (gain 1000) was designed at input interface. The input impedance of amplifier must be high to avoid loading of thermocouple signals. (Ratio of receiver to source impedance must be of the order 100).

3.3.1 D.C. Amplifier:

The following are the requirements of D.C. amplifier to amplify thermocouple and other low level signals.

1. High Input and low output impedance.
2. High common mode rejection.
3. High stability.
4. Good linearity in the range of operation.

3.3.2 Design Considerations:

The thermocouple signals are in the range of 0 to 3.5 millivolts for the temperature range 0°C to 100°C. The floating low level signals obtained from thermocouple is amplified to the range specified by

Analog to Digital Converter (ADC). The output of the amplifier should be floating since the Relay Multiplexer in system requires the floating input.

A variable gain d.c. differential amplifier is designed, so that the same amplifier may be used for other transducers output to be coupled to computer input. The specifications decided for amplifier are:

1. Floating input and floating output.
2. Zero Offset arrangement.
3. Gain settings of $\pm$ 1000, $\pm$ 500, $\pm$ 200, $\pm$ 100, $\pm$ 50, $\pm$ 20 and $\pm$ 10 are available, so that all types of transducer output can be matched to computer input requirement.
4. Powered by external supplies + 12 and -12 volts.

This amplifier can be used for one signal and in each low level signal line requires a separate unit.

DESIGN:

To achieve a differential gain of 1000 with high common mode rejection ratio, the use of operational amplifier is most appropriate. Since the output of available Op. Amp. is single ended, it is necessary to introduce a differential pair at output stage. The differential pair is used at the output stage, since the differential output can be obtained at the collectors of matched pair.

As the output stage can provide some gain, the gain requirements of the first stage can be reduced, and greater stability can be achieved in each stage. The output stage is designed for a fixed gain of 10. The various gain settings are obtained by changing the feed back resistance in steps. The Block Diagram is shown in Fig. 3.3.1.

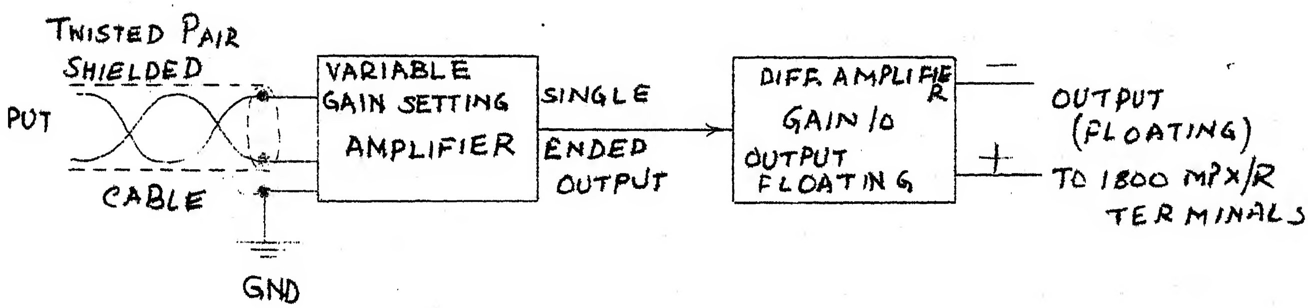


FIG. 3.3.1: BLOCK DIAGRAM of INPUT INTERFACE

FIRST STAGE:

Operational amplifier μA 741 is used as shown in Fig. 3.3.1 to accept differential input. Gain settings are changed by changing the feed back resistor instead of input resistor so as to maintain constant input impedance independent of gain settings. Identical resistor switching is 'provided between noninventing terminal of op-Amp and the ground, because of specified gain requirement. This is also essential to ensure uniform common mode rejection and low drift requirement. The offset compensation arrangement recommended by the manufactures is followed and can be adjusted by the variable resistance provided for the purpose.

The typical input bias current of μA 741 is 200 nano amperes. The parallel combination of Rf and Rin must be such that the bias current flowing through this combination will not develope a voltage comparable to the signal which is 0.2 millivolts.

Therefore the parallel combination of feed back resistor (R_f) and input resistor (R_{in}) should be much less than 1 K Ω. Since for high gains parallel combinations of R_f and R_{in} is approximately equal to R_{in}. A practical value of R_{in} selected is 200 Ω. Therefore a 220 Ω resistor is used at the input side of operational amplifier.

The calculated values for required gain settings are tabulated below. The maximum closed loop gain required from this stage is 100.

gain	$R_f = A.R_{in}$
100	22.0 K Ω
50	11.0 K Ω
20	4.4 K Ω
10	2.2 K Ω
5	1.1 K Ω
2	440 Ω
1	220 Ω

DESIGN OF SECOND STAGE:

After first stage of amplification, the signal amplitude is of the order of 100 millivolts. The second stage is designed for differential output with a gain of 10. RCA 3028 I.C. op. amp. has been selected for this stage as it provides matched pair with a built in current source. Since the matched transistors are on the same chip, their thermal and electrical characteristics are identical. The differential output is obtained at the collectors of matched pair. Zero offset balance is provided at this stage by

Note: 1% Precision resistors are used for exact gain requirements.

controlling the injection of current at the base of one matched pair transistor. A variable resistance is connected between the collectors of matched pair transistors, to provide gain control.

The complete design has been worked out and the final values are shown in Fig. 3.3.2.

3.4 OUTPUT INTERFACE:[14]

The output interface is required to regulate the power dissipation across the heating element- thus regulating the heat input to the tank.

The analog output available from Digital to Analog Converter in the system -1800 is utilized as control signal. For the designed interface, the output of Analog Driver Amplifier is used as a control signal because of impedance matching problems. Analog Driver Amplifier provided in the system is a single ended, high gain differential amplifier, with a closed loop gain of two.

The Analog Driver Amplifier output is utilized as a reference signal to a unit which provide a gate (drive) voltage to the thyristor. Depending on the level of reference signal, the firing angle of thyristor is decided. The firing angle control regulates the flow of average current to the heater and hence the heat dissipation. The S.C.R. conduction angle can be varied from 0° to 180°.

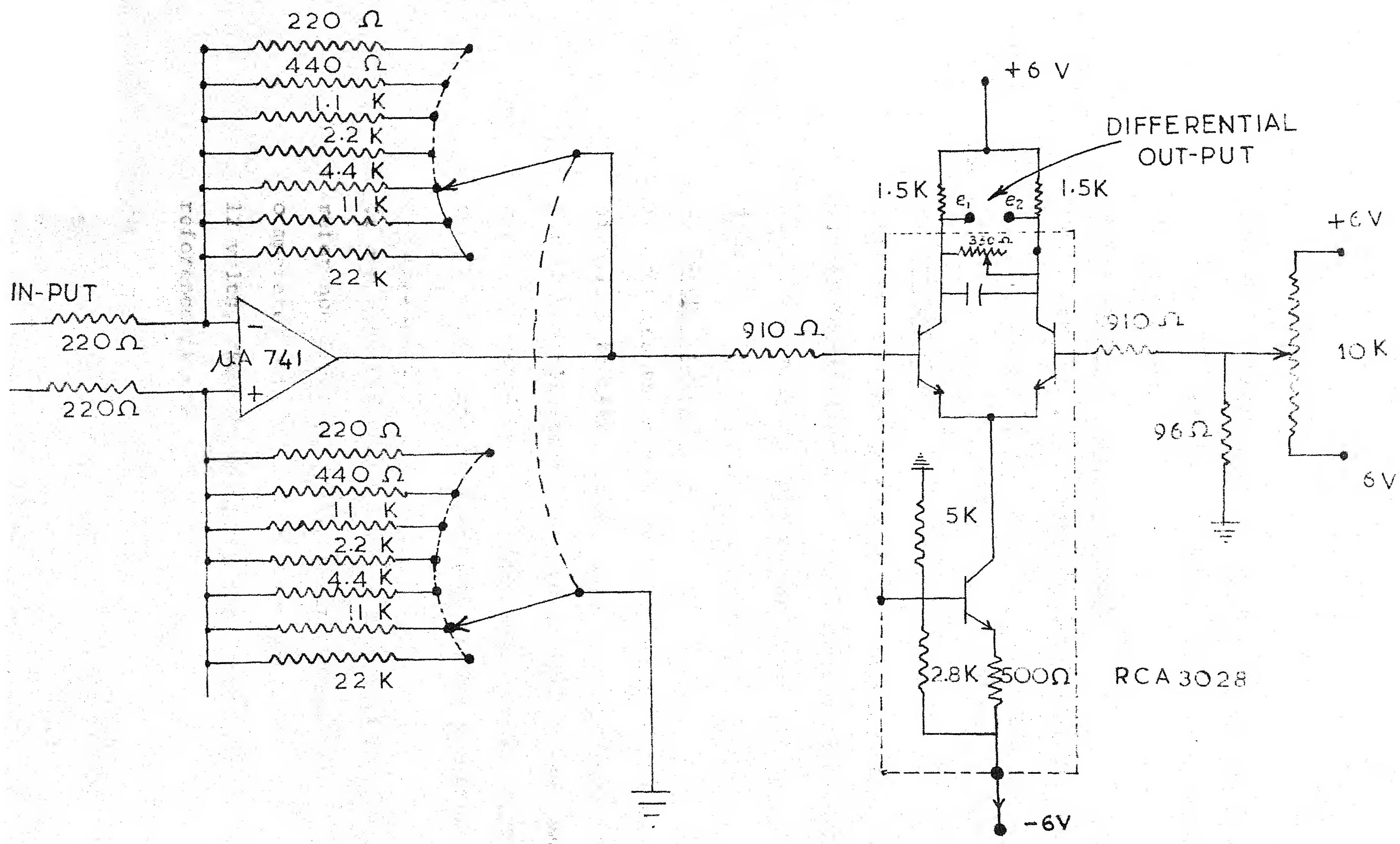


FIG. 3.3.2 VRIABLE GAIN DIFFERENTIAL AMPLIFIER

The unit comprises of two parts.

1. Thyristor Firing Circuit
2. Load Circuit.

3.4.1 Thyristor Firing Circuit:[22]

The block diagram for the firing circuit is shown in Fig. 3.4.1. The function of different blocks are described below:

1. Input Buffer:

This is provided to prevent the loading of reference signal (control signal) which comes from computer A.D.A. An emitter follower has been used for this job.

2. Sweep Generator:

It provides the sweep for half cycle of the a.c. signal. A bootstrap sweep generator has been designed for this application. Maximum voltage of the sweep can be adjusted by a potentio meter provided. The sweep voltage has been adjusted to be 5 volts.

3. Comparater:

It compares the sweep voltage level (0-5 v) with reference level (0-5 v), obtained from A.D.A. The comparater output level is changed from 0 volts to 12 volts, when the sweep voltage becomes more than reference signal.

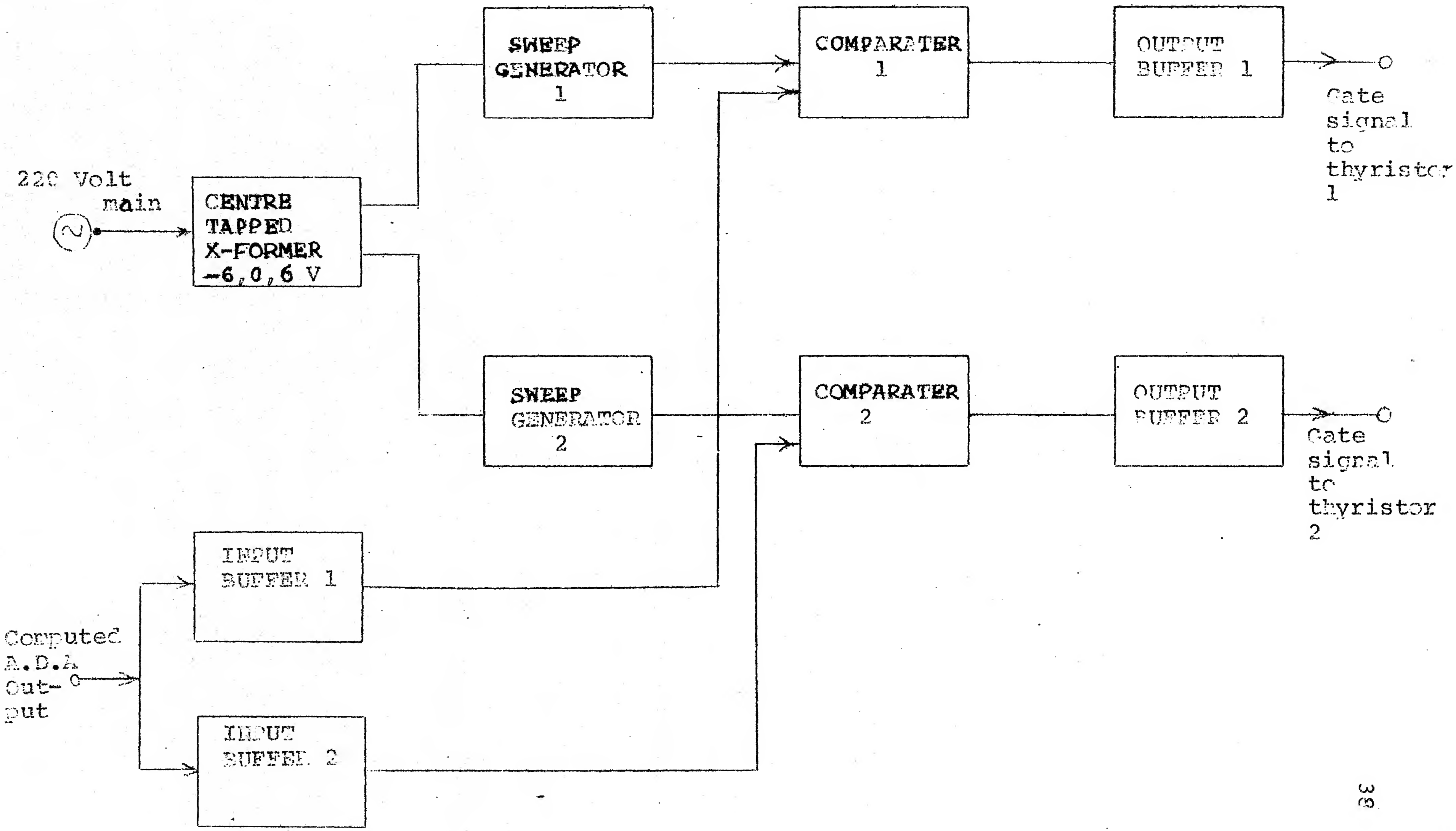


FIG. 3.4. 1: Firing Circuit.

4. Output Buffer:

It is required to reduce the comparater output level from 12 volts to 2 volts, as required by the specifications of S.C.R. gate voltage.

The one channel which comprises of all these blocks, gives firing pulse which controls the current flow through thyristor for half cycle only. To achieve control for complete cycle, one more channel 'channel 2' is used which operates in 180° phase difference.

The operation of this circuit is represented in Fig. 3.4.2.

LOAD CIRCUIT:

This is the final control circuit, which regulates the flow of current through load. The load is connected as shown in Fig. 3.4.3. The diodes are connected to provide for the termination of other end of load. The transformer is used to avoid the grounding of S.C.R. The thyristors have been shunted by a resistance, capacitance combination to prevent the damage of S.C.R. against voltage surge.

In our case load is purely resistive, so voltage and current are naturally in phase, resulting in some what simpler method of control. Because of phase controlled mode of operation various harmonies are generated depending on the conduction angle. Care is taken

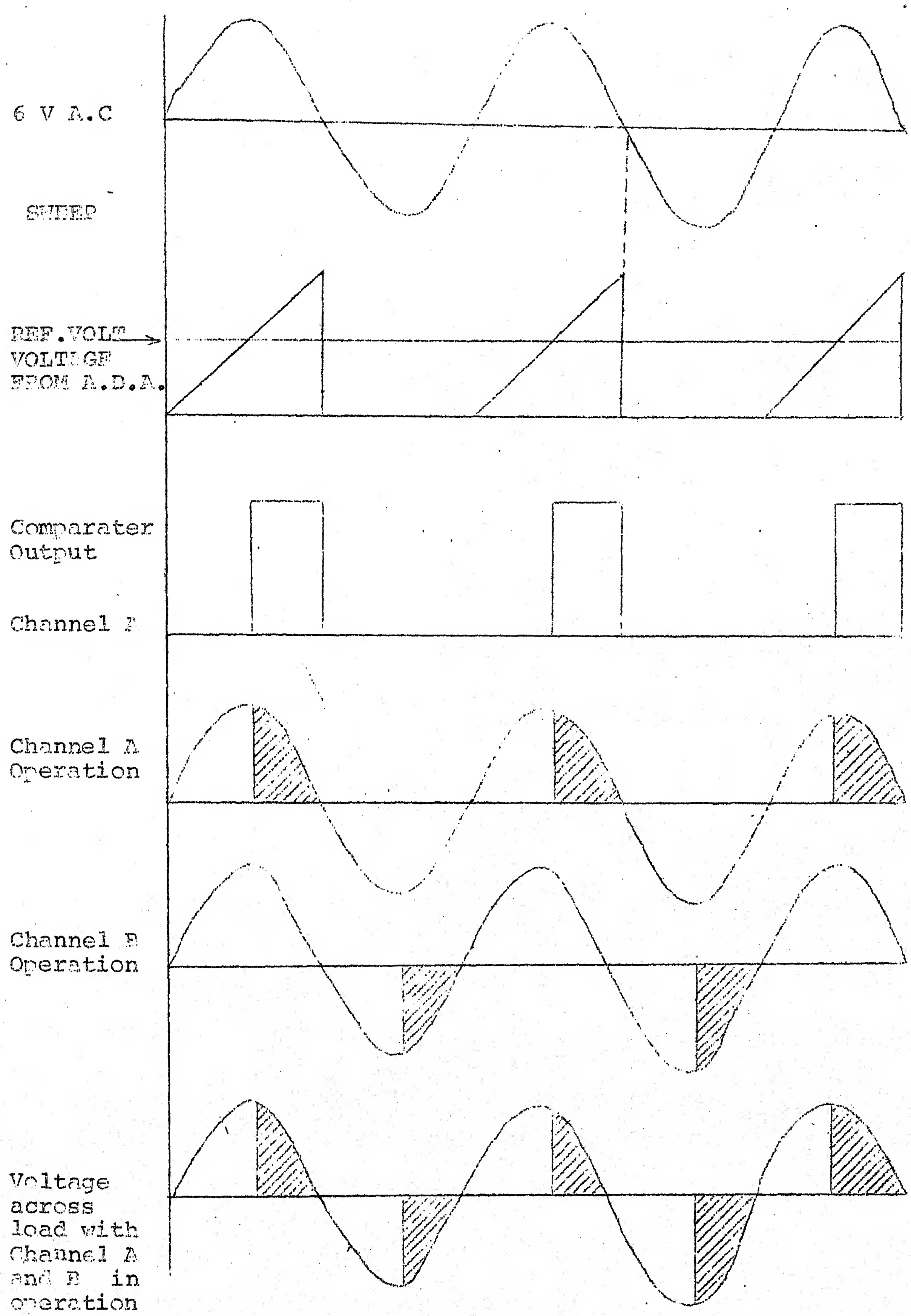


FIG. 3.4.2: Operation of Output Interface.

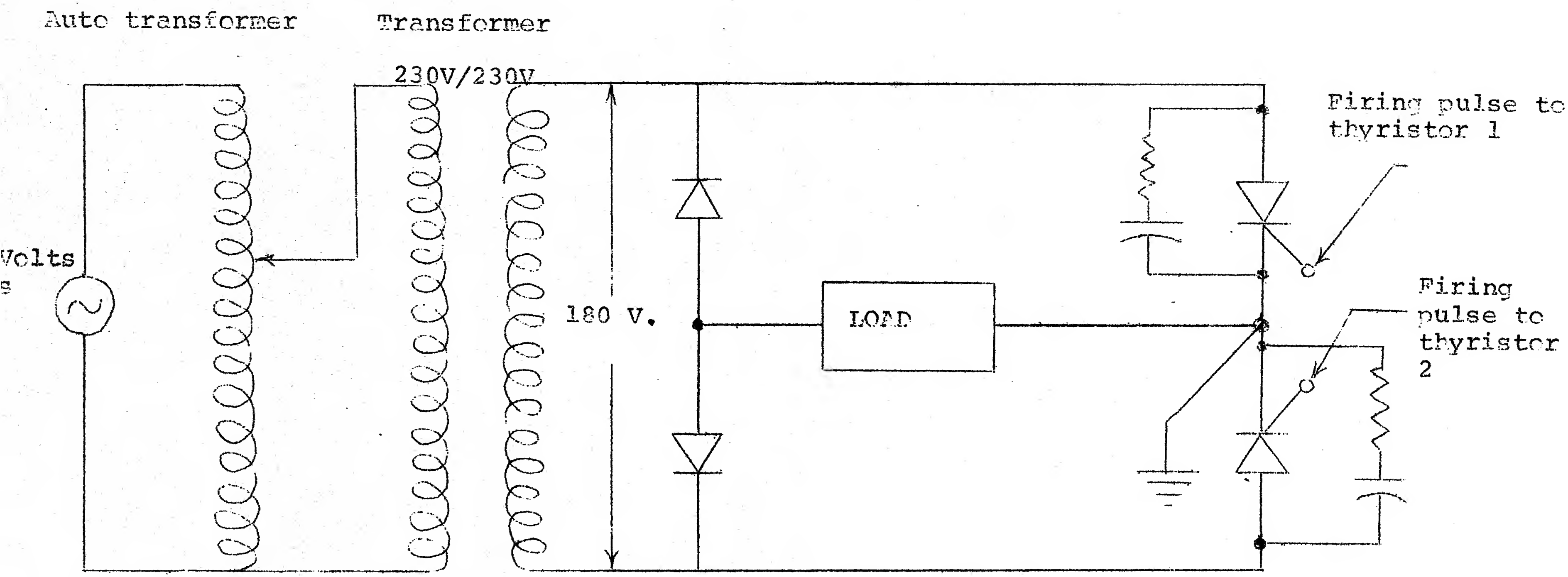


FIG. 3.4.3: LOAD CIRCUIT.

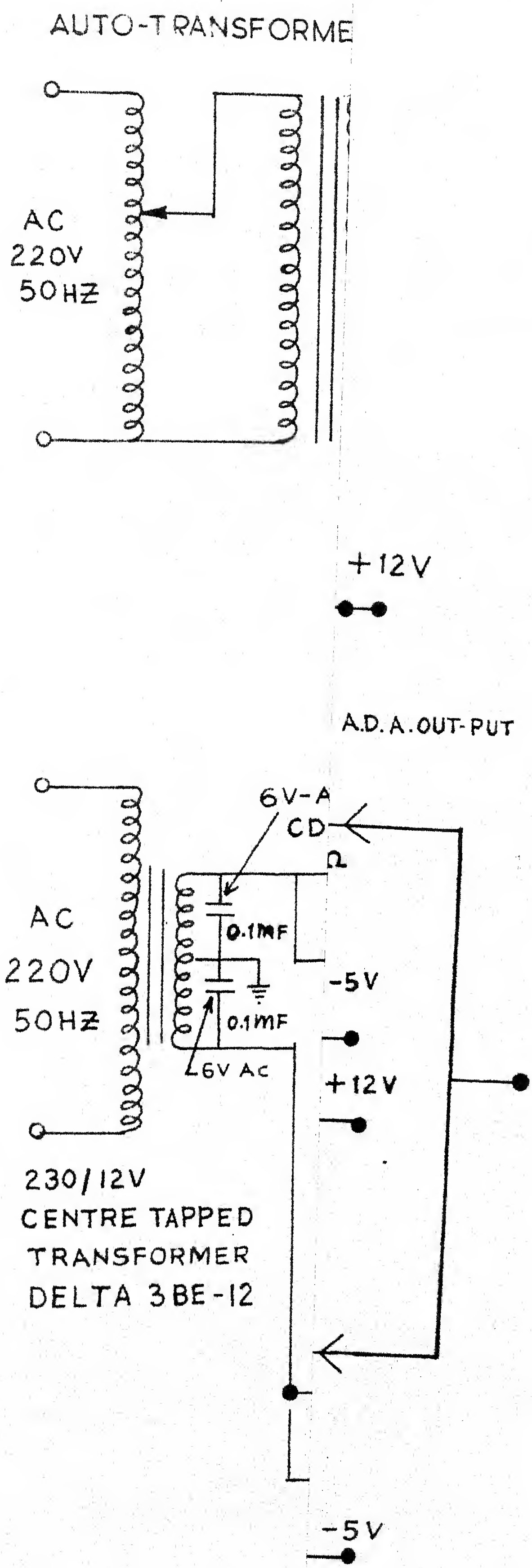
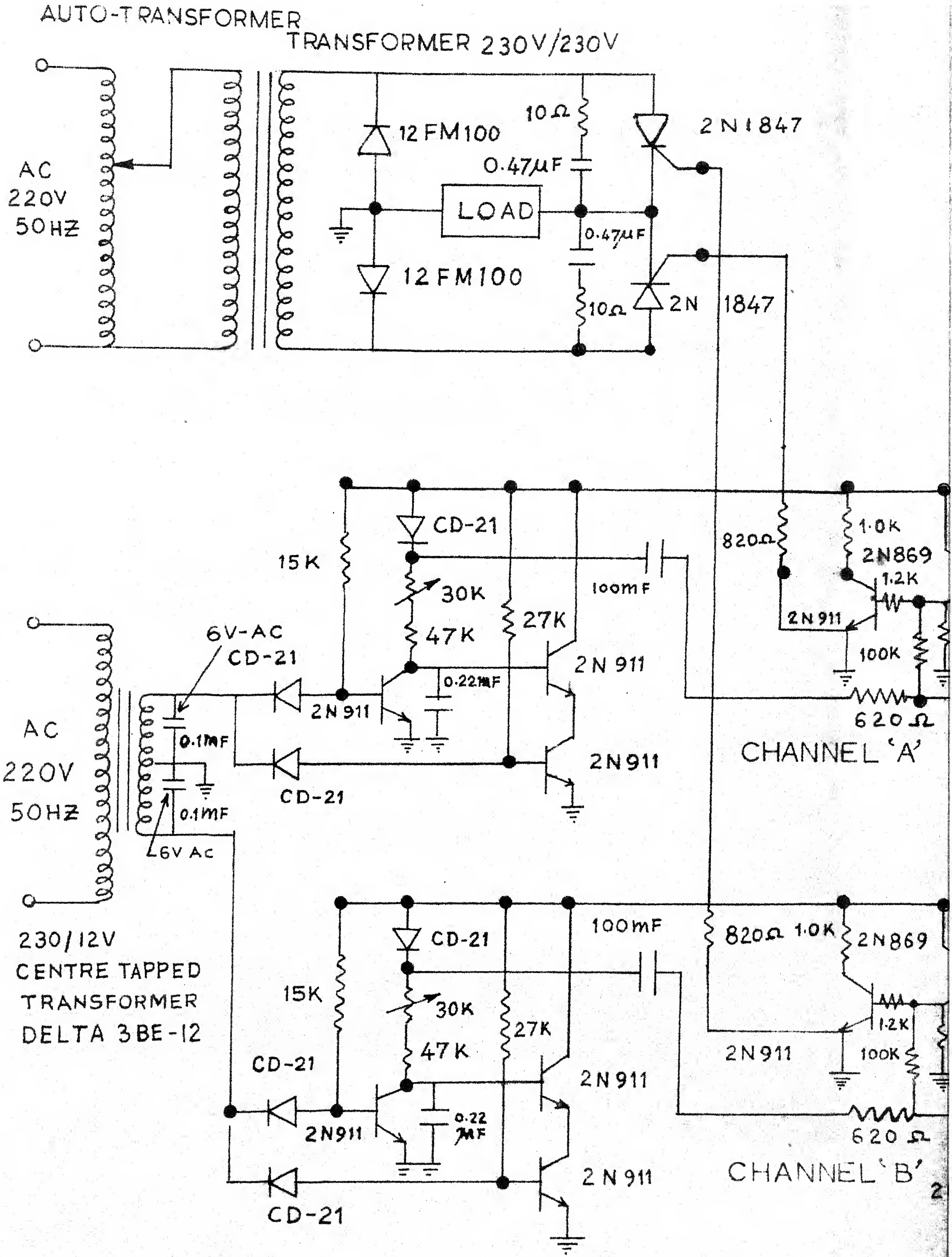
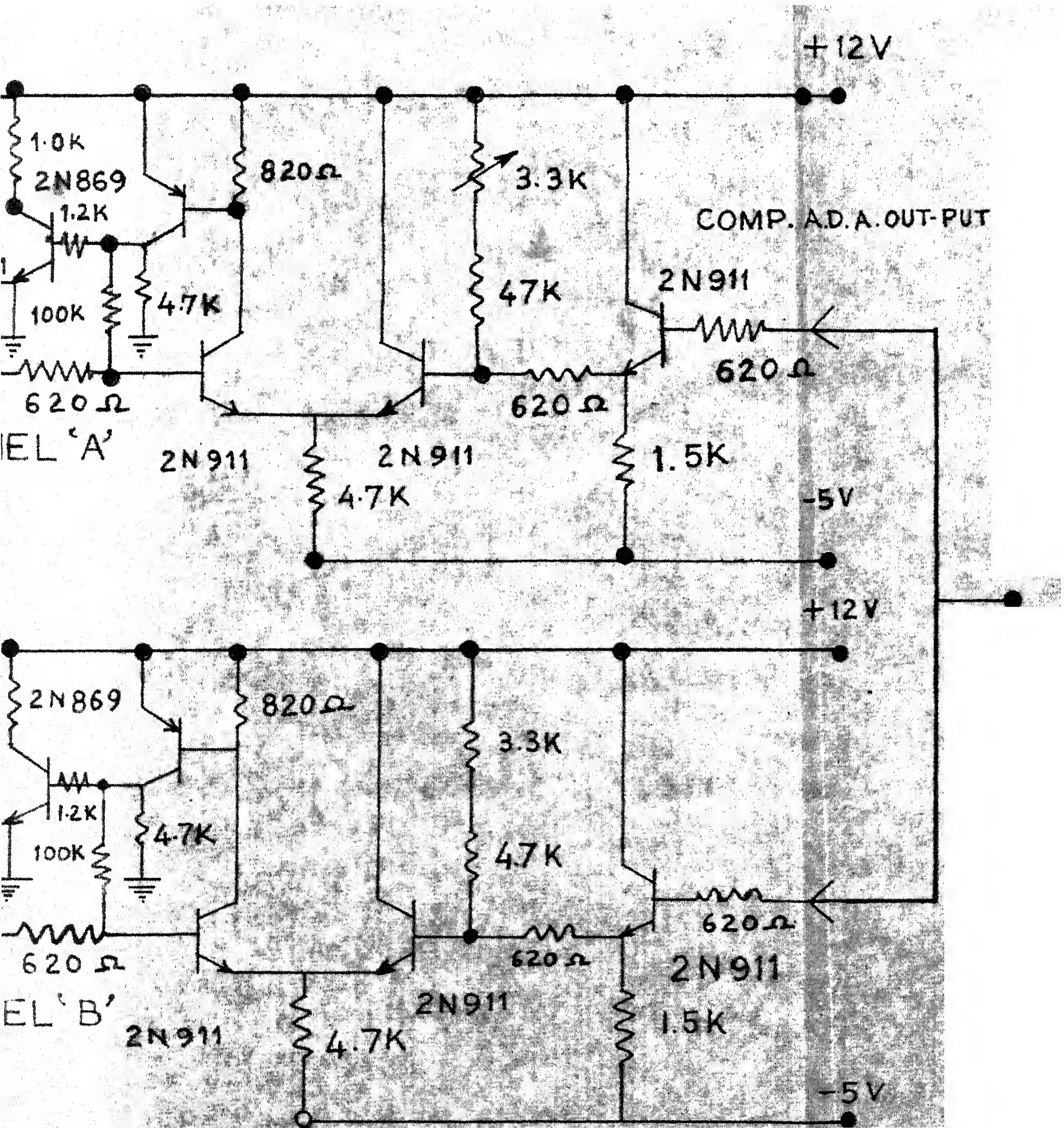


FIG. 3.4.4 POWER


AUTO-TRANSFORMER
TRANSFORMER 230V/230V
AC
220V
50HZ
12FM100
10Ω
0.47μF
2N1847
LOAD
0.47μF
12FM100
10Ω
2N
1847
CD-21
15K
30K
47K
27K
100mF
820Ω
1.0K
2N869
1.2K
2N911
100K
620Ω
6V-AC
CD-21
0.22MF
2N911
2N911
2N911
AC
220V
50HZ
0.1MF
0.1MF
6V AC
CD-21
CHANNEL 'A'
230/12V
CENTRE TAPPED
TRANSFORMER
DELTA 3BE-12
CD-21
100mF
820Ω
1.0K
2N869
15K
30K
27K
47K
1.2K
2N911
100K
CD-21
2N911
2N911
0.22
MF
620Ω
CHANNEL 'B'
2N911
CD-21

2



+12V
1·0K
2N869
1.2K
820Ω
3.3K
COMP. A.D.A. OUT-PUT
100K
4·7K
47K
2N911
620Ω
620Ω
620Ω
EL 'A'
2N911
2N911
1.5K
4·7K
-5V
+12V
2N869
820Ω
3.3K
1.2K
4·7K
100K
47K
620Ω
620Ω
620Ω
2N911
EL 'B'
2N911
2N911
1.5K
4.7K
-5V

about the shielding of signal lines in the vicinity of this equipment, because of the power frequency harmonic generation.

Fig. 3.4.4 represents the complete design of output interface.

CHAPTER 4

SOFTWARE

Some aspects of the software required is described in section 2.4. The complete scheme is described below.

When a switch is closed at the process terminals, a contact closure is recognized at Process Interrupt Status Word (PISW) bit 03. The PISW bit 03 is wired at Interrupt Level Status Word (ILSW) bit 00. The programs for reading analog voltages and control signal generation etc. can not be executed at level zero, because all the process I/O devices and disk are attached at higher interrupt level. The highest interrupt level at which the program can be executed is at level 6 (Appendix 3). This program is executed at basic level. The process programs are executed at higher priority than non process programs.

On recognition of an interrupt at PISW bit 3, the arrangement to queue a core-load 'PMESS' at basic level, is obtained by including a sub-routine 'INT1' in Executive. The cycling of control program is achieved by including 'SCAN' routines in Executive. Four SCAN routines are included in the system executive. The included routines SCAN, SCAN1, SCAN2 and SCAN3, provides for the cycling of another coreload 'ANLOG' at different intervals of time. . These routines are written utilizing the COUNT routines facility provided by system

Subroutine Library. The routines also test, the number of times 'ANLOG' has been executed and terminate their execution after 120 times. The routines INT1 and SCAN's are included in the system at system generation time by a * INCLD card. The various SCAN routines are included in system to see the effect of sampling period on control.

When INT1 has been executed, the interrupt level 00 is reset and program 'PMESS' is queued 'PMESS' is a queueable coreload and is stored on disk mounted as drive zero. The Variable Core (V Core) is saved on the disk in Nonprocess Save Area before 'PMESS' is loaded on the memory.

The coreload 'PMESS' gives message to the operator on typewriter 1 and asks some information about the process. The operator feeds the desired information to computer through keyboard. After the information is received, the program starts COUNT routine which inturn queues coreload ANLOG at specified intervals.

Coreload 'ANLOG' consists of a main program and three subroutines as given below:

1. 'ANLOG   Main program
2. 'READ'   Read MPX/R point 1
3. 'CNTRL'   Control program
4. 'DISPL'   Control output is converted to analog form and is transmitted to process.

Fig. 4. 1 explains about the various coreloads and subroutines. The program flow is also represented in this figure.Flow chart represented in Fig. 4. 2 represents the interrupt servicing procedure.

4.1 BRIEF DISCUSSION ABOUT CORELOADS & SUBROUTINES:

The functions of various coreloads and subroutines are discussed in brief below. The routines used in programs are classified below:

1. Routines included in Executive.
2. Routines required for main program ANLOG.

4.1.1 Executive Routines:

A. 'INT01' Routine: This routine is in executive interrupt servicing routine. This services the interrupt at PISW bit 3. It queues a coreload 'PMESS'.

B. Routine 'SCAN': It is a 'COUNT' routine included in executive. The number allotted to this count

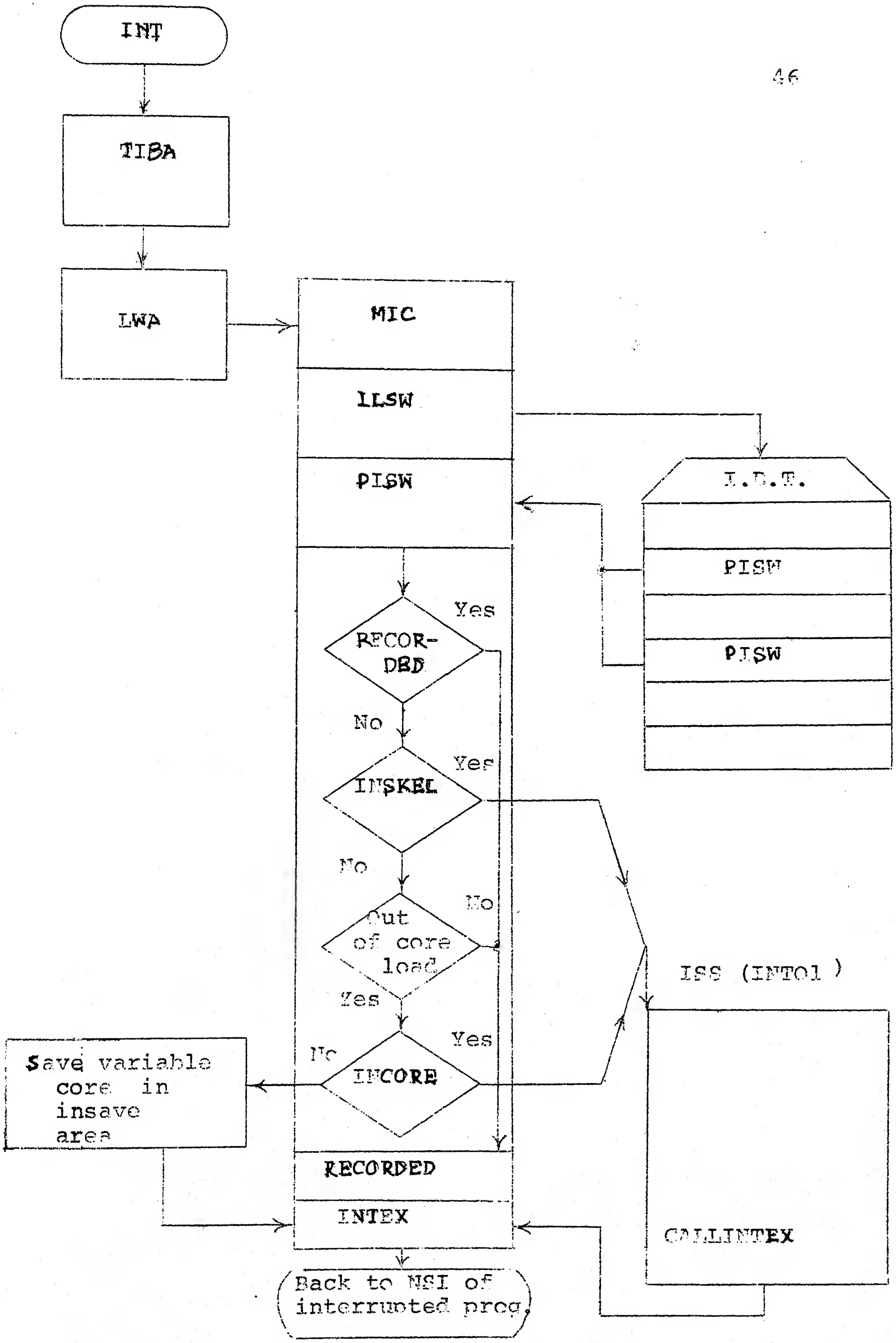


FIG 4.2 SERVICING OF PROCESS INTERRUPT

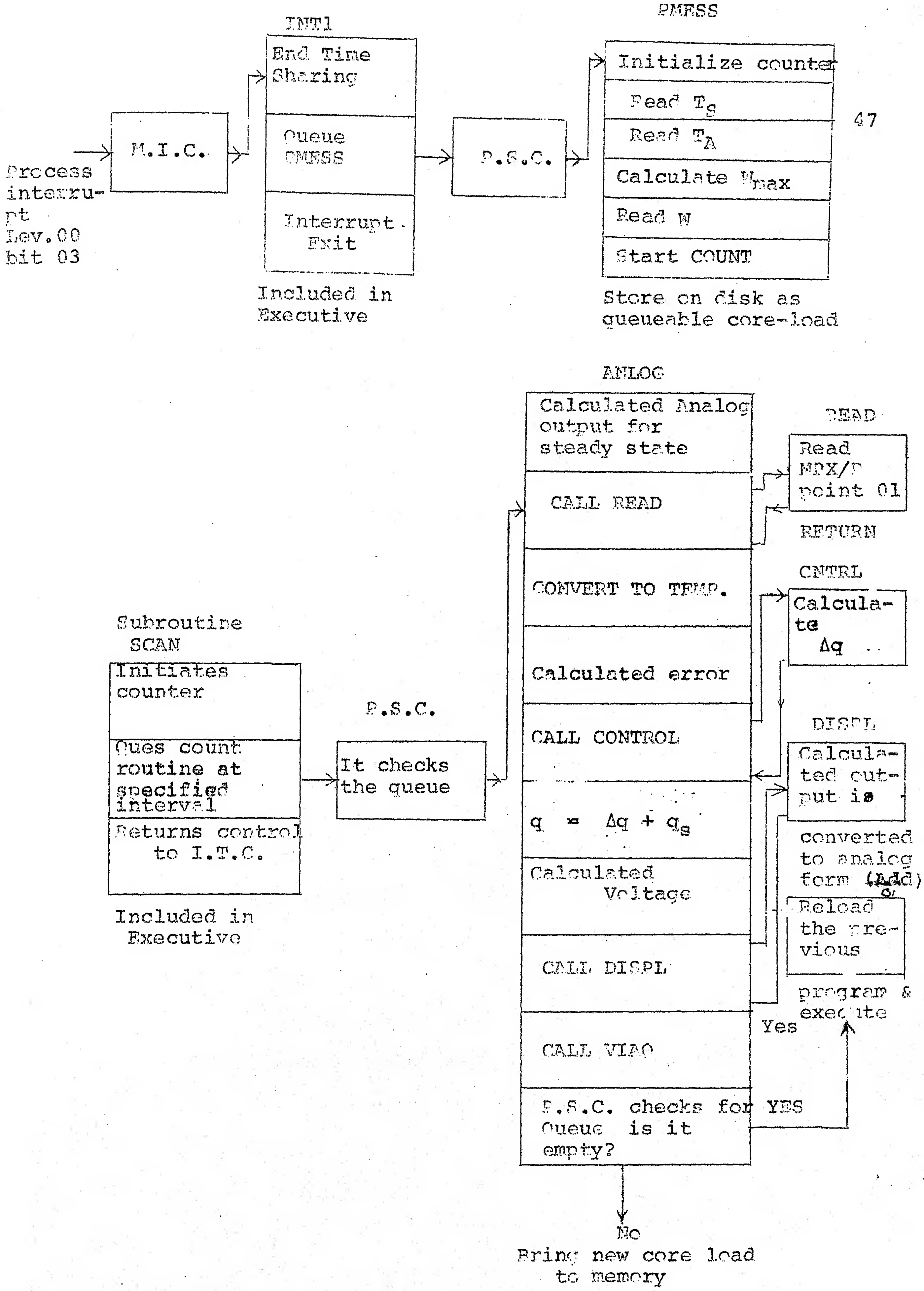


FIG. 4.1 : VARIOUS CORE LOADS IN PROGRAM.

routine is 5. It ends the time sharing and queues coreload 'ANLOG' 120 times. It provides for the periodic Execution of 'ANLOG' after every 60 seconds.

C. Routine SCAN1. It is a 'COUNT' routine included in Executive. The number allotted to this count routine is 2. It ends the time sharing and queues coreload 'ANLOG' 120 times, after every 10 seconds.

D. Routine SCAN2. It is a 'COUNT' routine included in Executive. The number allotted to this count routine is 3. It ends the time sharing and queues coreload 'ANLOG' 120 times after every 30 seconds.

E. Routine SCAN3. It is a 'COUNT' routine included in Executive. The number allotted to this count routine is 4. It ends the time sharing and queues coreload 'ANLOG' 120 times after every 2 minutes.

4.1.2 Main Program & Its Routines:

A. Main Program 'ANLOG': Main program 'ANLOG' finds the steady state power required for the given flow, setpoint temperature, ambient temperature and reads voltage at MPX/R point 01 on first iteration. At the second iteration it reads analog voltage at MPX/R point 01 converts it

to corresponding temperature. This conversion is achieved by the thermocouple calibration(App I) curve. After reading the tank temperature it finds the error (error = Set Point temperature read) and adjusts control output voltage accordingly.

B. Routine 'READ': It reads multiplexer point 01 and stores the value in location 'AREA'.

C. Routine 'CNTRL': It finds control output as a function of 'error', determined by main program 'ANLOG'.

D. DISPL: The output value calculated by routine 'CNTRL' is converted to analog form and is brought at Digital to Analog Converter output terminal (Address 01).

4.2 CORE LOADS:

A. Core Load 'PMESS': It is a main line queuable coreload reads, set point temperature, ambient temperature and finds out the value of the flow. It instruct the operator to adjust the flow rate less than the specified value. The adjusted flow rate is informed to Jomputer by the operator. Set point temperature, ambient temperature and flow rate adjusted are stored in 'INSKEL COMMON' area.

B. Core Load 'ANLOG': It is described in Section 4.1.2.

4.3 OFF LINE PROGRAMS DEVELOPED:

Two off line programs were developed. The function of these programs are discussed briefly here.

4.3.1 Polynomial Fitting Routines:

It fits the best polynomial for the set of data obtained from process. This program has been used for following calibrations.

a. Thermocouple calibration

b. Input Rotameter Calibration

c. Output Rotameter Calibration

d. Power Control Unit Calibration.

4.3.2 'PLOT' Routine:

It is a XY plot program, which has been used for following applications:

1. 'Thermocouple Calibration'
2. Temperature Vs. Time plot for controlled and uncontrolled operation.

Note: Flow chart (Appendix E) explains in detail the sequence of operations of various core loads.

CHAPTER 5

RESULTS and DISCUSSIONS

The designed input and output interfaces were used to connect the process with the computer. The designed interfaces were caliberated and caliberation curve equations were obtained using least square fit. The software package has been written for reading the temperature of tank and control of temperature, so as to minimize the errors arising due to fluctuations in load or change in set point. So as to prove the effectiveness of the interfaces and control program, an experiment was conducted as an example in which the response of digital control system to a step. Change in disturbance signal is observed. The observed results show that the controlled variable settles down around the set point. The results show small fluctuations in controlled variable, which might be due to sustained variations in load variables like flow rate or change in mains voltage supplied to heater. However control variable does settle down to steady state value within 5 minutes of the disturbacne. The results are shown in Figure 5.0.

The following factors contribute to the errors introduced in the system.

1. Error associated with thermocouple measurement device:

The present experimental set up does not include any arrangement to compensate for the variation of reference junction temperature. These variations alter the caliberation curve coefficients, which results in incorrect recording of temperature. The differential amplifier introduced in input signal line may also introduce some drift, which may alter the output voltage from actual value and hence introduce some error in recording of temperature. Some stray pick-up in signal line may also alter the voltage at multiplexer terminals. A suitable designed RC filter will attenuate the pick up to considerable standard.

2. Noise introduced in system because of sampling.

Because of sampling at relay multiplexer terminals some noise is introduced in the measured signal voltage. A digital filter introduced in the control loop will considerably improve the response.

5.1 Suggestions for further improvement and work

1. There should be some method to indicate to computer and operator, if the thermocouple junction measuring the temperature breaks.

2. Compensatory networks which takes into account of variation of reference junction temperature should be included in measurement circuit.

3. Some basic assumptions made during the development of control model like constant head of water in stirred tank and flow rates, are not true in the present physical system.

The pumps used in the system for maintaining constant flow rates, results in sustained oscillations in the system. This can be improved by the gravity flow scheme.

4. The other heat losses in the system have not been considered in the model, as such the system has to be insulated thoroughly to minimize radiation loses.

5. Optimum sampling period should be determined so as to avoid high computer cost and maintaining desired accuracy.

APPENDIX I

NOISE IN INSTRUMENT CIRCUIT AND ITS REDUCTION METHODS[18,19]

Different type noise which influence the process signal are classified below and their reduction procedure is discussed.

I.1 STATIC NOISE:

Electrical voltages around the process get capacitively coupled to the wires in instrument circuit. Because of this coupling an a.c. noise signal is superimposed on d.c. process signal and is transmitted across the wires in instrument circuit. Low level signals are greatly affected by this noise.

Coupling between external sources and instrument circuit is broken by means of a static shield, which is properly grounded.

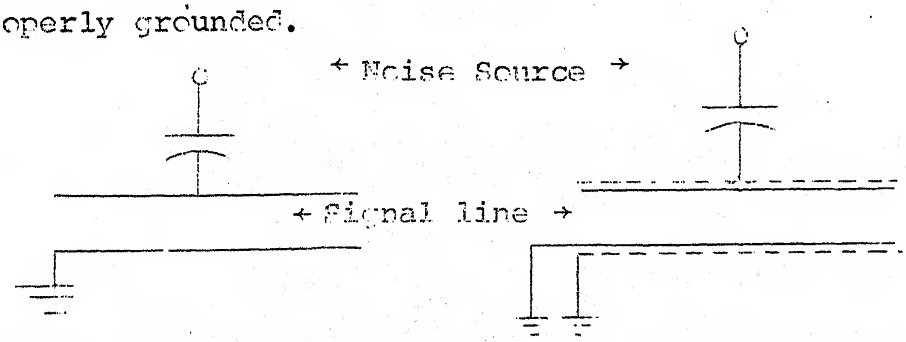


Fig.1: Coupling shown

Fig.2: Coupling broken by shield.

I.2 MAGNETIC NOISE:

This noise is generated due to the stray magnetic fields present. Stray magnetic fields are produced around a conductor carrying current.

As a result, all power lines, moters- transformers etc; radiate magnetic fields of erratic and varying strengths. Anytime magnetic fields are coupled to thermocouple loop, noise current flowing through transducer loop produces a noise voltage. The noise voltage is in turn superimposed on voltage being transmitted by the pair of wires.

Following are the two methods used to avoid magnetic noise.

1. Twisting the wires in transducer loop: In this case wire pair forms a series of loops in signal circuit. This way adjacent loops cancel the effect of induced magnetic field.
2. Shielding the signal wires: It cancels any magnetic field, through the production of eddy currents, with in the shield material.

<u>COMMON MODE NOISE:</u>

Varying ground potentials at different points in the experimental set-up cause common mode noise. If both the thermocouple and computer terminals are grounded, varying ground potentials cause circulating current. The presence of common mode signal is not a source of major error. But in practice "Common Mode Voltage" is converted to a differential signal which adds to the true signal. The common/mode noise is particularly

troublesome in thermocouple circuit. The process of converting common mode voltage to differential voltage in a system is very complex due to distributed leakages and capacitances in actual system.

AVOIDING COMMON MODE NOISE:

The source of common mode noise is avoided by using differential input, so that neither input terminal is grounded. Even with this arrangement, common mode noise can be caused by ground metal objects close to the wires which cause charging current to flow through capacitive coupling. In thermocouple circuit two instrument wires have different resistances, so the resulting voltage drop appears as common mode noise. This cause of C.M. noise is eliminated by placing a shield around the wires and grounding it at thermocouple, so that wires and shield are at the same potential. If shield is grounded away from thermocouple, differing ground potential will cause common mode noise. Common mode noise reducing arrangement is shown in Fig. (c).

In thermocouple circuit, all the above mentioned noise is avoided by taking thermocouple wires small in length, and connecting it to twisted pair shielded wire. The shield is grounded at thermocouple end. Before feeding the thermocouple signals to computer,

amplification is needed. So a differential amplifier with high/common mode rejection capability is to be designed.

The relay multiplexer provided in system 1800 helps a great deal in improving common mode rejection. Common mode source is being disconnected for the period during which particular input is not being measured.

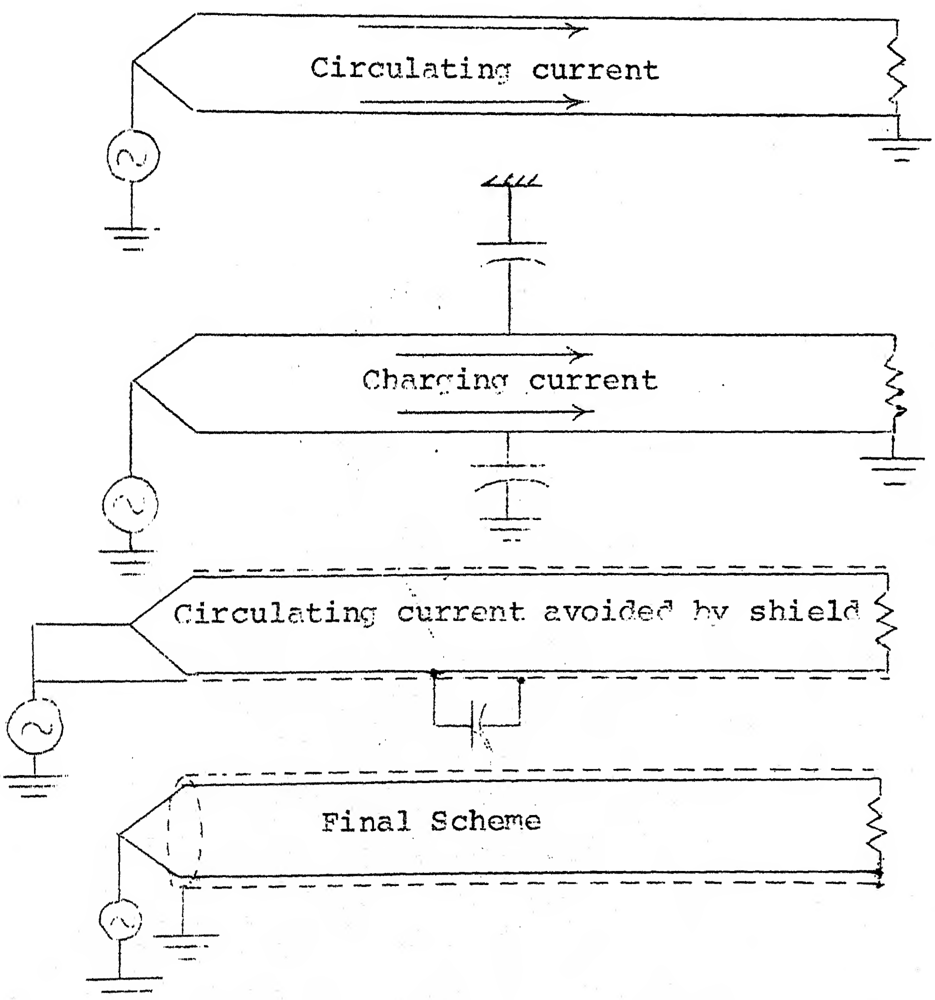


Fig. C: Common mode noise reduction.

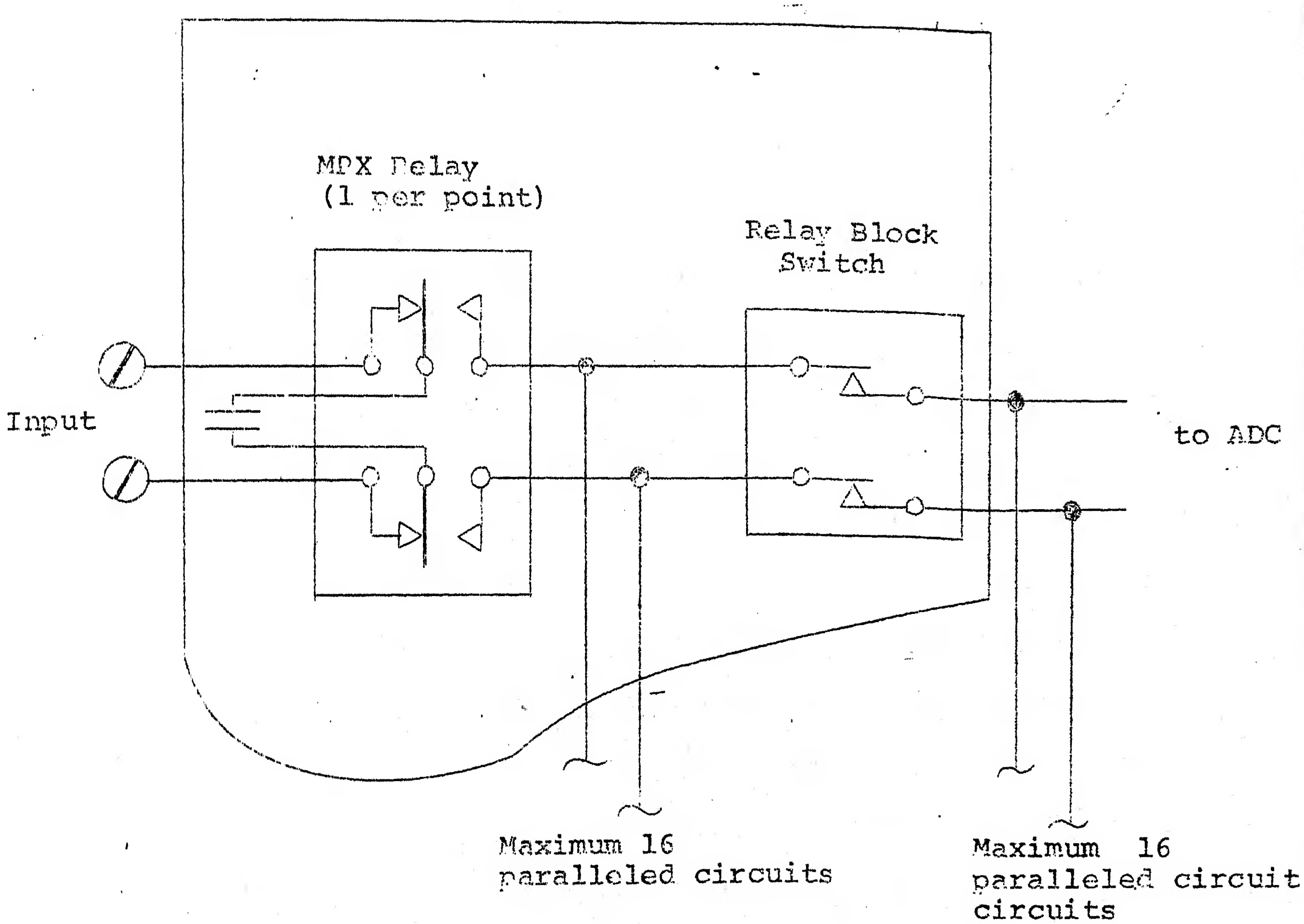


Fig. d: Relay Multiplexer Signal Paths.

APPENDIX II

THERMOCOUPLE CALIBRATION [10]

Thermocouple calibration is required to determine the temperature of the hot junction. Since the thermocouple develops a voltage depending on the temperature difference of hot and cold junction. If a relationship is known between difference in temperature between junction (when reference voltage is kept constant) and voltage developed, we can directly find the temperature of hot junction.

PROCEDURE:

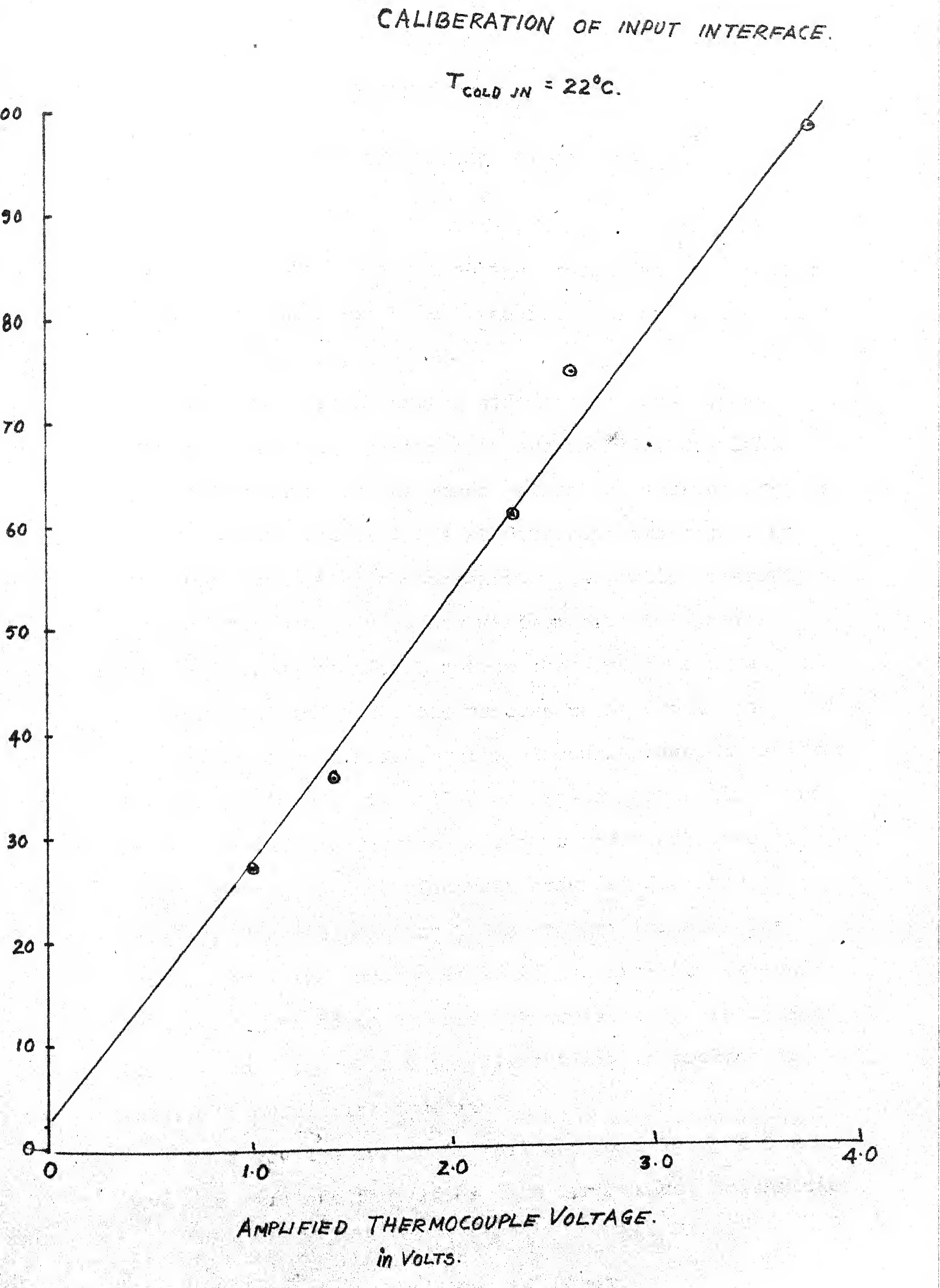
The temperature in the bath is maintained constant and the corresponding voltage developed from thermocouple is measured. The number of readings are taken for one steady state value and their mean is found out. Approximately five such readings are taken and a curve is fitted for the minimum error.

The equation of the fitted curve is given in attached sheet. A plot of temperature Vs. signal voltage is shown in Fig. II-1.

SOURCES OF ERROR:

1. The accuracy of thermocouple. It varies from $0.5^{\circ}C$ to $2^{\circ}C$.
2. Heat distribution between the medium, where the temperature is being measured.

3. Variation of Cold junction temperature.
4. The accuracy of measurement is largely dependent on the installation of thermocouple.
5. The current drawn from thermocouple also affects the voltage developed.


CALIBERATION OF INPUT INTERFACE.
$T_{COLD\ JN} = 22°C.$
00
90
80
70
60
50
40
30
20
10
0
0
1·0
2·0
3·0
4·0
AMPLIFIED THERMOCOUPLE VOLTAGE.
in VOLTS.

APPENDIX III

TSX-SYSTEM GENERATION FOR IBM 1800 [1,20]

The time sharing Executive, i.e. the operating system which controls the entire process and nonprocess programs is tailored to the requirements of process that is to be controlled.

IBM provides a general software package, which supports the total features of system 1800. The 1800 system may have various memory sizes and various process I/O's and nonprocess I/O's at different installations. The idea is to make a operating system, which takes up minimum core thereby giving maximum core for process and nonprocess coreloads and at the same time have maximum facilities for the process to be controlled.

This part of building the Executive system tailored to our requirement is called as "System Generation" and is done using the 'Equate' cards provided with the program package. The manufacturer provided deck has the facility for all existing I/O's and utilities. The Equate cards are equated to 1, if the facility is available and desired to be used, otherwise they are equated to 0. Thus it provides the flexibility to include or exclude a particular facility.

This way the system is tailored exactly to I/O's we have, as well the facilities like Dump Trace, Arithmatic

trace that we need. The SYSTEM GENERATION also tailors the disk areas to our needs; i.e. we would have more temporary working storage or more fixed core image area. The other aspects of SYSGEN is that it assigns Logical Unit Numbers (LUN) to various I/O devices, to be called in FORTRAN programs. It also includes the user's subroutine and loads library decks in the Executive for fast response.

A complete listing of EQUATE CARDS and their value is attached, (Appendix III-a). With the current Equate Cards memory requirement is calculated. It takes approximately 7 K words of the memory leaving 9 K words for Variable Core.

PROCEDURE:

The step by step procedure for system generation is described in IBM 1800, TSX operating procedures.

```
// JOB                                                              TSK00010
// ASM TASK                                                         TSK00020
*OVERFLOW SECTORS 32                                                TSK00050
*PUNCH                                                              TSK00060
                HDNG    USER EQUATE CARDS GROUP 1                   TSK00065
                ABS                                                 TSK00070
************** USER GROUP 1 EQUATE CARDS FOLLOW   ***              TSK00080
CORSZ  EQU      16      OBJECT CORE SIZE * 8,16,32 *                TSK00090
COMSZ  EQU      50      OBJECT INSKEL COMMON MAX WD SIZ             TSK00100
CORSP  EQU      4     CORE SPEED,2 IF 2US,4 IF 4US   M9             TSK00105
DORG1  EQU      1     0 IF ONE DISK DR,ELSE 1                       TSK00110
DORG2  EQU      0     0 IF TWO DISK DR,ELSE 1                       TSK00120
PRIL0  EQU      1     DISK DR 0 INTER.LEVEL * 0/23 *                TSK00130
PRIL2  EQU            DISK DR 2 INTER.LEVEL * 0/23 *                TSK00150
PRIL1  EQU      1     DISK DR 1 INTER.LEVEL * 0/23 *                TSK00140
TORG   EQU      1     0 IF SYSTEM HAS NO 1816,ELSE 1                TSK00160
TORG1  EQU      0     0 IF 1 1053 OR 1816 ON GP1,ELSE 1             TSK00170
TORG2  EQU      1     0 IF 2 1053 OR 1816 ON GP1,ELSE 1             TSK00180
TORG3  EQU      1     0 IF 3 1053 OR 1816 ON GP1,ELSE 1             TSK00190
TORG4  EQU      1     0 IF NO 1816 ON GP1,ELSE 1                    TSK00200
TORG5  EQU      1     0 IF NO 1053 OR 1816 PRS ON GP2,              TSK00210
TORG6  EQU      0     0 IF 1 1053OR1816 ON GP2,ELSE 1               TSK00220
TORG7  EQU      1     0 IF 2 1053OR1816 ON GP2,ELSE 1               TSK00230
TORG8  EQU      1     0 IF 3 1053OR1816 ON GP2,ELSE 1               TSK00240
TORG9  EQU      1     0 IF NO 1816 ON GP2,ELSE 1                    TSK00250
TORGN  EQU      1     0 IF SYSTEM HAS NO 1053OR 1816                TSK00260
BLAST  EQU      0   1 IF BLAST CMD FOR 1053,ELSE 0   M9             TSK00265
TYPL1  EQU      3   1053/1816 GP1 INTER.LEVEL                       TSK00270
TYPL2  EQU      3   1053/1816 GP2 INTER.LEVEL                       TSK00280
INTK1  EQU      6     USER KB REQ RTN INT LVL, KB1  3.7             TSK00290
INTK2  EQU      8     USER KB REQ RTN INT LVL, KB2  3.7             TSK00295
NOBUF  EQU      1     0 IF NO DISK MSG BUFFERING,ELSE 1             TSK00300
NOCYL  EQU      4       NO.OF CYLS FOR MSG BUFFER                   TSK00310
NUMBE  EQU      8       NO.OF NON-PROC MSG BUFF SECTORS             TSK00320
BZ1    EQU      60      MSG UNIT SIZE,1053-1,GP1                    TSK00330
BZ2    EQU      0       MSG UNIT SIZE,1053-2,GP1                    TSK00340
BZ3    EQU      0       MSG UNIT SIZE,1053-3,GP1                    TSK00350
BZ4    EQU      0       MSG UNIT SIZE,1053-4,GP1                    TSK00360
BZ5    EQU      60      MSG UNIT SIZE,1053-1,GP2                    TSK00370
BZ6    EQU      0       MSG UNIT SIZE,1053-2,GP2                    TSK00380
BZ7    EQU      0       MSG UNIT SIZE,1053-3,GP2                    TSK00390
BZ8    EQU      0       MSG UNIT SIZE,1053-4,GP2                    TSK00400
PORG   EQU      0     0 IF NO 1443, ELSE 1             MOD01        TSK00405
```

```
[illegible] EQU        LIST PR..0 IF 1053,1 IF 1443      TSK00420
SCRG1  EQU      0   SYSTEM PR..0 IF 1053,1 IF 1443    TSK00430
SLCRG  EQU      1   WHICH OF  3 1053/1816 +S SY/LST P TSK00440
ECPT1  EQU      0   0 IF EAC PR IS 1053,1 IF 1443     TSK00450
ECPT2  EQU      1   EAC TYPWR COMBINATICNS *1 TO 15 * TSK00460
ECPT3  EQU      0   0 IF EAC TYP CN GP1,ELSE 1        TSK00470
CDINS  EQU      0    1 CARD I/O IN SKELETON  0 ELSE   TSK00480
CRDNO  EQU      0   0 IF 1 1442, ELSE 1               TSK00490
CRLF1  EQU      0   0 IF NO OVLP AN.IN.BASIC,ELSE 1.  TSK00500
CRLF2  EQU      0   0 IF NC CVLP AN.IN.EXPN.,ELSE 1.  TSK00510
PTSKP  EQU      0   0,EXITS TO EAC.1,LCCPS UNTIL RDY. TSK00520
CONTA  EQU      7   LEVEL OF USER CCNS.INT.RTN.       TSK00530
NULEV  EQU      12  TOTAL NO.LEVELS AT FINAL TSX TIME TSK00540
MKLEV  EQU      0   0 IF 14 OR LESS INT LEVELS,ELSE 1 TSK00550
PRICS  EQU          0 IF STANDARD,ELSE 1              TSK00560
TRORG  EQU      1   0 IF NO UTILITIES,ELSE 1          TSK00570
TA01   EQU      1   0 IF NO TRACE,ELSE 1              TSK00580
TA02   EQU      1   0 IF NO ADDR.STOP,ELSE 1          TSK00590
TA03   EQU      1   0 IF NO DISK CUMP,ELSE 1          TSK00600
ONLIN  EQU      1   1 SYS. GEN. FUNC. INCLUDED 0 NONE TSK00610
```

```
****************************************************** TSK65020
BDT1   EQU     DT5  DT1 IF NO BACKUP OR NOT USED       TSK65030
BDT2   EQU     DT2  DT2 IF NO BACKUP OR NOT USED       TSK65040
BDT3   EQU     DT3  DT3 IF NO BACKUP OR NOT USED       TSK65050
BDT4   EQU     DT4  DT4 IF NO BACKUP CR NOT USED       TSK65060
BDT5   EQU     DT1  DT5 IF NO BACKUP OR NOT USED       TSK65070
BDT6   EQU     DT6  DT6 IF NO BACKUP OR NOT USED       TSK65080
BDT7   EQU     DT7  DT7 IF NO BACKUP CR NOT USED       TSK65090
BDT8   EQU     DT8  DT8 IF NO BACKUP CR NOT USED       TSK65100
       END     STP00                                   TSK65110
```

```
LVPR1 EQU          1443 INTERRUPT LEVEL                TSK00410
LORG1 EQU          LIST PR..0 IF 1053,1 IF 1443        TSK00420
SCRG1 EQU     0    SYSTEM PR..0 IF 1053,1 IF 1443      TSK00430
SLCRG EQU     1    WHICH OF  8 1053/1816 +S SY/LST P   TSK00440
ECPT1 EQU     0    0 IF EAC PR IS 1053,1 IF 1443       TSK00450
ECPT2 EQU     1    EAC TYPWR COMBINATIONS *1 TO 15 *   TSK00460
ECPT3 EQU     0    0 IF EAC TYP ON GP1,ELSE 1          TSK00470
CDINS EQU     0     1 CARD I/O IN SKELETON  0 ELSE     TSK00480
CRDNO EQU     0  0 IF 1 1442, ELSE 1                   TSK00490
CRLF1 EQU     0    0 IF NO OVLP AN.IN.BASIC,ELSE 1.    TSK00500
CRLF2 EQU     0    0 IF NO OVLP AN.IN.EXPN.,ELSE 1.    TSK00510
PTSKP EQU     0    0,EXITS TO EAC.1,LOOPS UNTIL RDY.   TSK00520
CONTA EQU     7    LEVEL OF USER CONS.INT.RTN.         TSK00530
NULEV EQU     12   TOTAL NO.LEVELS AT FINAL TSX TIME   TSK00540
MKLEV EQU     0  0 IF 14 OR LESS INT LEVELS,ELSE 1     TSK00550
PRICS EQU        0 IF STANDARD,ELSE 1                  TSK00560
TRORG EQU     1    0 IF NO UTILITIES,ELSE 1            TSK00570
TA01  EQU     1    0 IF NO TRACE,ELSE 1                TSK00580
TA02  EQU     1    0 IF NO ADDR.STOP,ELSE 1            TSK00590
TA03  EQU     1    0 IF NO DISK DUMP,ELSE 1            TSK00600
ONLIN EQU     1    1 SYS. GEN. FUNC. INCLUDED 0 NONE   TSK00610

************************************************** TSK65020
BDT1  EQU     DT5  DT1 IF NO BACKUP OR NOT USED      TSK65030
BDT2  EQU     DT2  DT2 IF NO BACKUP OR NOT USED      TSK65040
BDT3  EQU     DT3  DT3 IF NO BACKUP OR NOT USED      TSK65050
BDT4  EQU     DT4  DT4 IF NO BACKUP OR NOT USED      TSK65060
BDT5  EQU     DT1  DT5 IF NO BACKUP OR NOT USED      TSK65070
BDT6  EQU     DT6  DT6 IF NO BACKUP OR NOT USED      TSK65080
BDT7  EQU     DT7  DT7 IF NO BACKUP OR NOT USED      TSK65090
BDT8  EQU     DT8  DT8 IF NO BACKUP OR NOT USED      TSK65100
```

```
// JCB
// *LIST OF SYSTEM DIRECTOR EQUATE CARDS
// ASM SDEQU                                                            SYD00020
// ASM SDFQU                                                            SYD00020
*SAVE SYMBOL TABLE                                                      SYD00040
                   ABS                                                  SYD00050
              NULEV EQU     12    NUMBER OF LEVELS USED                 SYD00060
              USEC0 EQU     1     1-LEVEL USED    0-NOT USED            SYD00070
              USEC1 EQU     1     1-LEVEL USED    0-NOT USED            SYD00080
              USEC2 EQU     1     1-LEVEL USED    0-NOT USED            SYD00090
              USEC3 EQU     1     1-LEVEL USED    0-NOT USED            SYD00100
              USEC4 EQU     1     1-LEVEL USED    0-NOT USED            SYD00110
              USEC5 EQU     1     1-LEVEL USED    0-NOT USED            SYD00120
              USEC6 EQU     1     1-LEVEL USED    0-NOT USED            SYD00130
              USEC7 EQU     1     1-LEVEL USED    0-NOT USED            SYD00140
              USEC8 EQU     1     1-LEVEL USED   0-NOT USED             SYD00150
              USEC9 EQU     1     1-LEVEL USED    0-NOT USED            SYD00160
              USE10 EQU     1     1-LEVEL USED    0-NOT USED            SYD00170
              USE11 EQU     1     1-LEVEL USED    0-NOT USED            SYD00180
              USE12 EQU     0     1-LEVEL USED    0-NOT USED            SYD00190
              USE13 EQU     0     1-LEVEL USED    0-NOT USED            SYD00200
              USE14 EQU     0     1-LEVEL USED    0-NCT USED            SYD00210
              USE15 EQU     0     1-LEVEL USED    0-NOT USED            SYD00220
              USE16 EQU     0     1-LEVEL USED    0-NOT USED            SYD00230
              USE17 EQU     0     1-LEVEL USED    0-NOT USED            SYD00240
              USE18 EQU     0     1-LEVEL USED    0-NOT USED            SYD00250
              USE19 EQU     0     1-LEVEL USED    0-NOT USED            SYD00260
              USE20 EQU     0     1-LEVEL USED    0-NOT USED            SYD00270
              USE21 EQU     0     1-LEVEL USED    0-NOT USED            SYD00280
              USE22 EQU     0     1-LEVEL USED    0-NOT USED            SYD00290
              USE23 EQU     0     1-LEVEL USED    0-NOT USED            SYD00300
              NB00  EQU     2     1+HIGHEST ILSW BIT = USED             SYD00310
              NB01  EQU     2     1+HIGHEST ILSW BIT = USED             SYD00320
              NB02  EQU     1     1+HIGHEST ILSW BIT = USED             SYD00330
              NB03  EQU     2     1+HIGHEST ILSW BIT = USED             SYD00340
              NB04  EQU     3     1+HIGHEST ILSW BIT = USED             SYD00350
              NB05  EQU     2     1+HIGHEST ILSW BIT = USED             SYD00360
              NB06  EQU     2     1+HIGHEST ILSW BIT = USED             SYD00370
              NB07  EQU     2     1+HIGHEST ILSW BIT = USED             SYD00380
              NB08  EQU     1     1+HIGHEST ILSW BIT = USED4            SYD00390
```

```
// JOB
// *LIST OF SYSTEM DIRECTOR EQUATE CARDS
// ASM SDEQU                                                      SYD00020
// ASM SDEQU                                                      SYD00020
*SAVE SYMBOL TABLE                                                SYD00040
                  ABS                                             SYD00050
              NULEV EQU    12       NUMBER OF LEVELS USED         SYD00060
              USE00 EQU    1        1-LEVEL USED   0-NOT USED     SYD00070
              USE01 EQU    1        1-LEVEL USED   0-NOT USED     SYD00080
              USE02 EQU    1        1-LEVEL USED   0-NOT USED     SYD00090
              USE03 EQU    1        1-LEVEL USED   0-NOT USED     SYD00100
              USE04 EQU    1        1-LEVEL USED   0-NOT USED     SYD00110
              USE05 EQU    1        1-LEVEL USED   0-NOT USED     SYD00120
              USE06 EQU    1        1-LEVEL USED   0-NOT USED     SYD00130
              USE07 EQU    1        1-LEVEL USED   0-NOT USED     SYD00140
              USE08 EQU    1        1-LEVEL USED  0-NOT USED      SYD00150
              USE09 EQU    1        1-LEVEL USED   0-NOT USED     SYD00160
              USE10 EQU    1        1-LEVEL USED   0-NOT USED     SYD00170
              USE11 EQU    1        1-LEVEL USED   0-NOT USED     SYD00180
              USE12 EQU    0        1-LEVEL USED   0-NOT USED     SYD00190
              USE13 EQU    0        1-LEVEL USED   0-NOT USED     SYD00200
              USE14 EQU    0        1-LEVEL USED   0-NOT USED     SYD00210
              USE15 EQU    0        1-LEVEL USED   0-NOT USED     SYD00220
              USE16 EQU    0        1-LEVEL USED   0-NOT USED     SYD00230
              USE17 EQU    0        1-LEVEL USED   0-NOT USED     SYD00240
              USE18 EQU    0        1-LEVEL USED   0-NOT USED     SYD00250
              USE19 EQU    0        1-LEVEL USED   0-NOT USED     SYD00260
              USE20 EQU    0        1-LEVEL USED   0-NOT USED     SYD00270
              USE21 EQU    0        1-LEVEL USED   0-NOT USED     SYD00280
              USE22 EQU    0        1-LEVEL USED   0-NOT USED     SYD00290
              USE23 EQU    0        1-LEVEL USED   0-NOT USED     SYD00300
              NB00  EQU    2        1+HIGHEST ILSW BIT = USED     SYD00310
              NB01  EQU    2        1+HIGHEST ILSW BIT = USED     SYD00320
              NB02  EQU    1        1+HIGHEST ILSW BIT = USED     SYD00330
              NB03  EQU    2        1+HIGHEST ILSW BIT = USED     SYD00340
              NB04  EQU    3        1+HIGHEST ILSW BIT = USED     SYD00350
              NB05  EQU    2        1+HIGHEST ILSW BIT = USED     SYD00360
              NB06  EQU    2        1+HIGHEST ILSW BIT = USED     SYD00370
              NB07  EQU    2        1+HIGHEST ILSW BIT = USED     SYD00380
              NB08  EQU    1        1+HIGHEST ILSW BIT = USED4    SYD00390
```

```
NB10  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00410
NB11  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00420
NB12  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00430
NB13  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00440
NB14  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00450
NB15  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00460
NB16  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00470
NB17  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00480
NB18  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00490
NB19  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00500
NB20  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00510
NB21  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00520
NB22  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00530
NB23  EQU   0     1+HIGHEST ILSW BIT = USED  SYD00540
NILC0 EQU   4     1+HIGHEST PISW BIT = USED  SYD00550
NILC1 EQU   0     1+HIGHEST PISW BIT = USED  SYD00560
NILC2 EQU   0     1+HIGHEST PISW BIT = USED  SYD00570
NILC3 EQU   0     1+HIGHEST PISW BIT = USED  SYD00580
NILC4 EQU   0     1+HIGHEST PISW BIT = USED  SYD00590
NILC5 EQU   4     1+HIGHEST PISW BIT = USED  SYD00600
NILC6 EQU   4     1+HIGHEST PISW BIT = USED  SYD00610
NILC7 EQU   0     1+HIGHEST PISW BIT = USED  SYD00620
NILC8 EQU   4     1+HIGHEST PISW BIT = UWED  SYD00630
NILC9 EQU   0     1+HIGHEST PISW BIT = USED  SYD00640
NIL10 EQU   0     1+HIGHEST PISW BIT = USED  SYD00650
NIL11 EQU   0     1+HIGHEST PISW BIT = USED  SYD00660
NIL12 EQU   0     1+HIGHEST PISW BIT = USED  SYD00670
NIL13 EQU   0     1+HIGHEST PISW BIT = USED  SYD00680
NIL14 EQU   0     1+HIGHEST PISW BIT = USED  SYD00690
NIL15 EQU   0     1+HIGHEST PISW BIT = USED  SYD00700
NIL16 EQU   0     1+HIGHEST PISW BIT = USED  SYD00710
NIL17 EQU   0     1+HIGHEST PISW BIT = USED  SYD00720
NIL18 EQU   0     1+HIGHEST PISW BIT = USED  SYD00730
NIL19 EQU   0     1+HIGHEST PISW BIT = USED  SYD00740
NIL20 EQU   0     1+HIGHEST PISW BIT = USED  SYD00750
NIL21 EQU   0     1+HIGHEST PISW BIT = USED  SYD00760
NIL22 EQU   0     1+HIGHEST PISW BIT = USED  SYD00770
NIL23 EQU   0     1+HIGHEST PISW BIT = USED  SYD00780
NLWS1 EQU   12    NO. PROG. INT. GROUP 0-13  SYD00790
NLWS2 EQU   0     NO. PROG. INT. GROUP 14-23 SYD00800
```

```
NITF1 EQU      16             NO. COUNT SUBRS. GROUP 1      SYD00810
NITF2 EQU      0              NO. COUNT SUBRS. GROUP 2      SYD00820
ICLL1 EQU      /004F          INT. CORELCAD LEVEL MASK      SYD00830
ICLL2 EQU      /FFFF          INT. CORELOAD LEVEL MASK      SYD00840
ITCUS EQU      1              1-ITC USED   0-NCT USED       SYD00850
TBASE EQU      -125           CLOCK BASE=MILSEC*TBASE       SYD00860
CBASE EQU      1              COUNT BASE=MILS*TBASE*CBASESYD00870
TIME1 EQU      /0000          TIMER C MILS*TBASE            SYD00880
TIME2 EQU      /03E8          TIMER C MILS*TBASE            SYD00890
NCRSP EQU      12, NO RESP TIME,VALUE BETW 1-127 M6         SYD00895
VCORE EQU      7000           ADDR. 1ST WORD VARIABLE CORSYD00900
NUQLE EQU      6              NUMBER OF QUEUE ENTRIES       SYD00910
DUMP1 EQU      0              1-EAC DUMP USED 0-NOT USED    SYD00920
CPMCI EQU      1              1-ITC RESETS 0-USER RESETS    SYD00930
TISHA EQU      30             PERIOD FOR TIME SHARING       SYD00940
TIMES EQU      1             1-TSC UXED 0-TSC NOT USED
```

APPENDIX IV

OUTPUT INTERFACE CALIBRATION

The output interface designed controls the power by controlling the firing angle of thyristor. When reference voltage is zero, the power is available for the complete cycle and when it is five volts, the firing angle is 180° and hence no power.

$t_1 = f(v)$

v is computer output voltage

V = Mains voltage

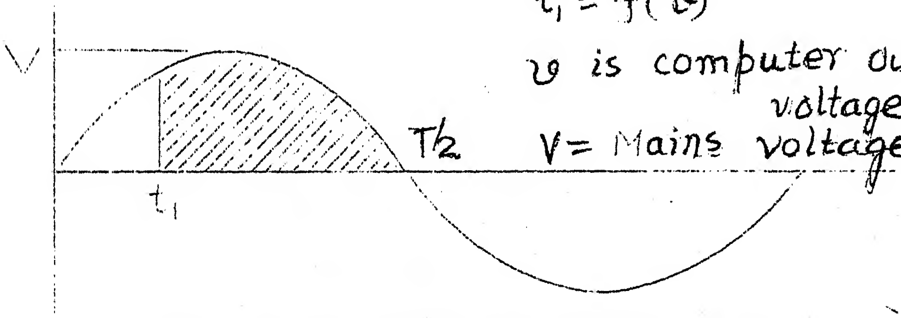


Fig. IV.1: Wave form across load.

$$t_1 = \frac{v}{5} \times \frac{T}{2}$$

$$P = \frac{2}{T} \int_{\frac{Tv}{10}}^{T/2} A^2 \sin^2 \frac{2\pi}{T} t \, dt$$

$$= \frac{2A^2}{T} \int_{\frac{Tv/\cancel{10}}{10}}^{T/2} \sin^2 \frac{2\pi}{T} t \, dt$$

$$= \frac{A^2}{T} \int_{\frac{Tv}{10}}^{T/2} (1 - \cos \frac{4\pi}{T} t) \, dt$$

$$= \frac{A^2}{T} \left[t - \frac{T}{4\pi} \cdot \sin \frac{4\pi}{T} t \right]_{\frac{Tv}{10}}^{T/2}$$

$$P = \frac{A^2}{T}\left[\left(\frac{T}{2} - \frac{T.v}{10} \right) - \frac{T}{4\pi} \left(\sin \pi - \sin \frac{\pi v}{5} \right) \right]$$

$$= A^2 \left(\frac{1}{2} - \frac{v}{10} \right) - \frac{A^2}{4\pi} \sin \frac{\pi v}{5}$$

$$= A^2 \left(\frac{1}{2} - \frac{v}{10} \right) - \frac{A^2}{4\pi} \left(\frac{\pi v}{5} - \frac{(\pi v)^3}{3!} + \frac{(\pi v)^5}{5!} \right)$$

$$= A^2 \left[\frac{1}{2} - v\left(\frac{1}{10} - \frac{1}{20} \right) - \frac{\pi^2 v^3}{24} + \text{higher order terms} \right]$$

$$= A^2 \left[\frac{1}{2} - \frac{v}{20} - \frac{\pi^2 v^3}{24} + \text{higher order terms} \right]$$

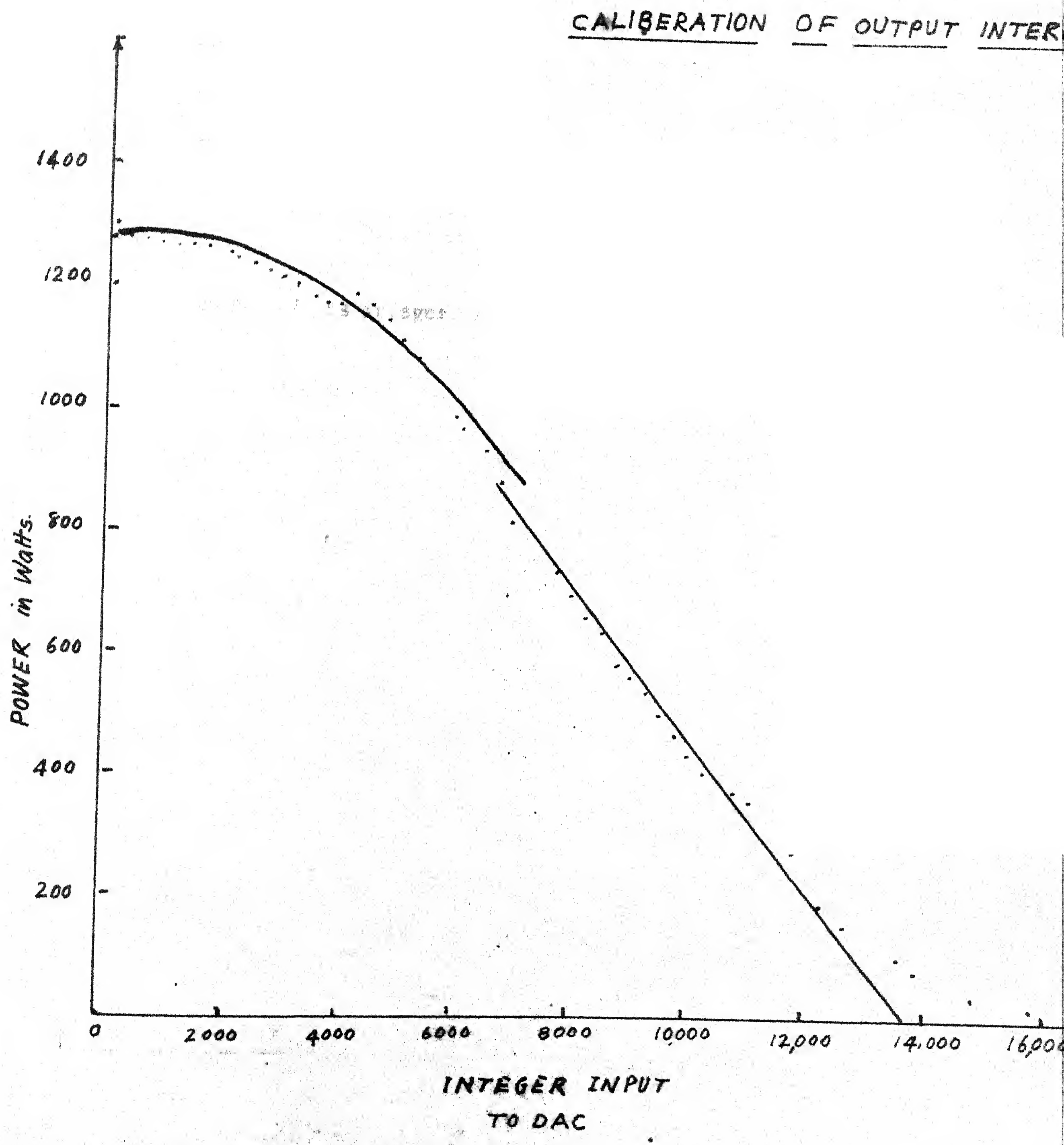
The above analysis shows that polynomial may be fitted for the caliberated datas.

Output Interface Caliberation :

The caliberation datas have been divided into two groups for better polynomial fitting (so as to get minimum average error for each group). The power verses integer number plot is shown in fig. IV-2 and the two curves are clearly shown.

The program is written for this purpose to sense the data switch status after pressing start and convert the value to analog form using DAC and ADA. The converted analog value is fed to signal input terminals of output interface.

The different signal voltages are given to output interface varying the data switches status and the output power is noted using a wattmeter. The polynomials fitted for two groups of


CALIBERATION OF OUTPUT INTER
POWER in Watts.
1400
1200
1000
800
600
400
200
0
2000
4000
6000
8000
10000
12,000
14,000
INTEGER INPUT
TO DAC

datas are the following :

$$P = -8.1489I + 13754.14 \qquad \text{when } I \leq 820$$

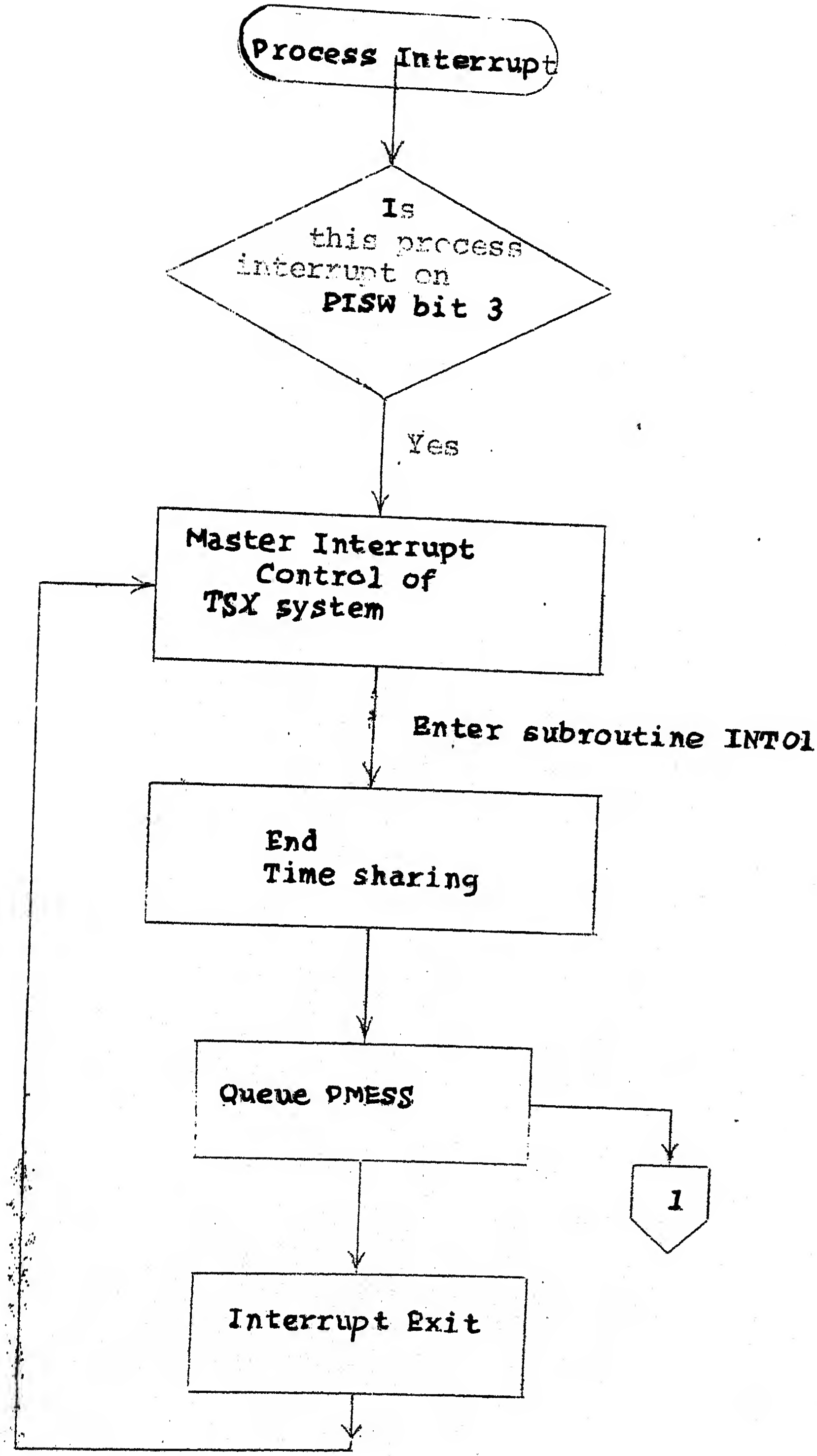
which gives maximum error $\leq$ 4.97 % and

$$P = -0.0288\, I^2 + 48.8934\, I - 13972.0472 \qquad \text{when } I \geq 820$$

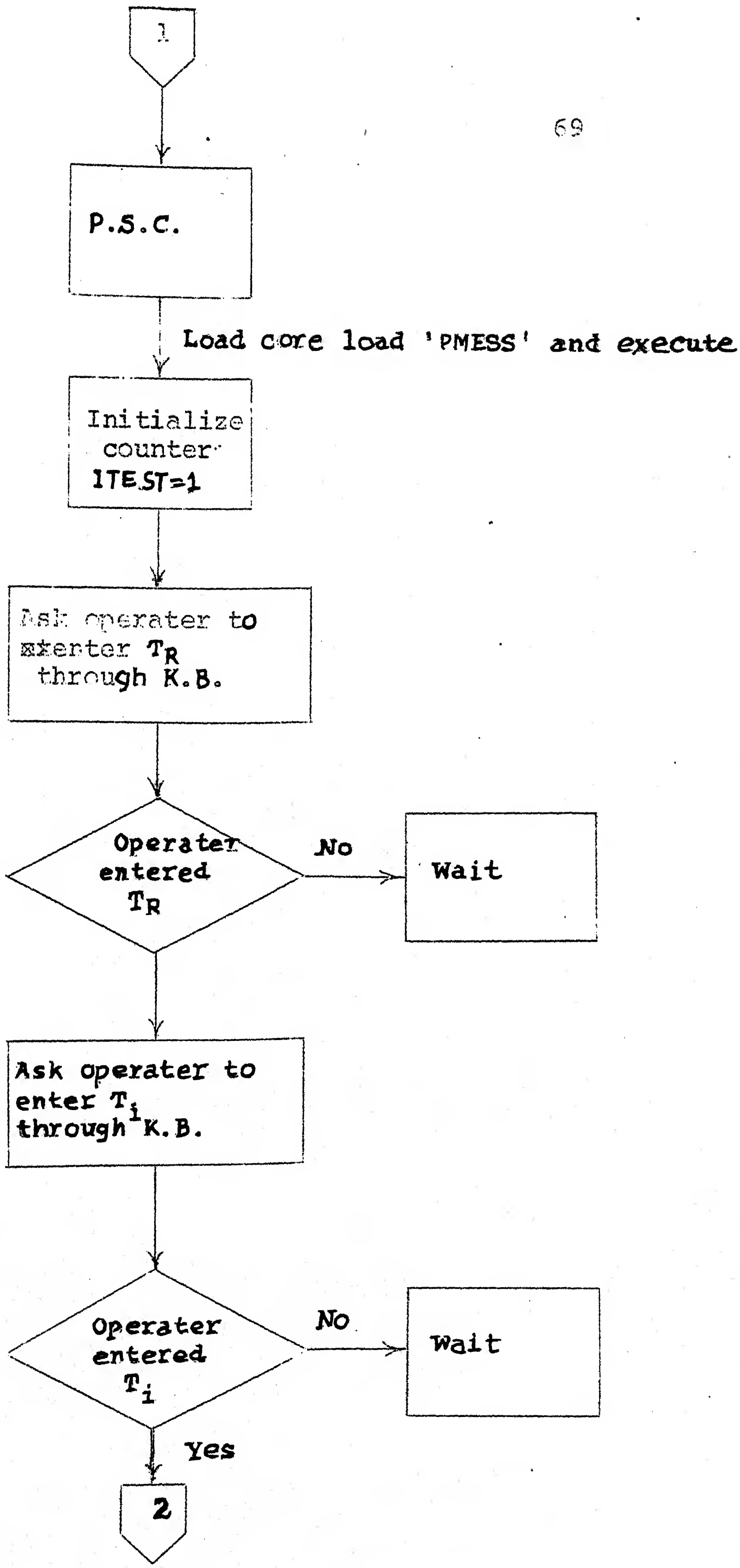
max. error : 4.66%

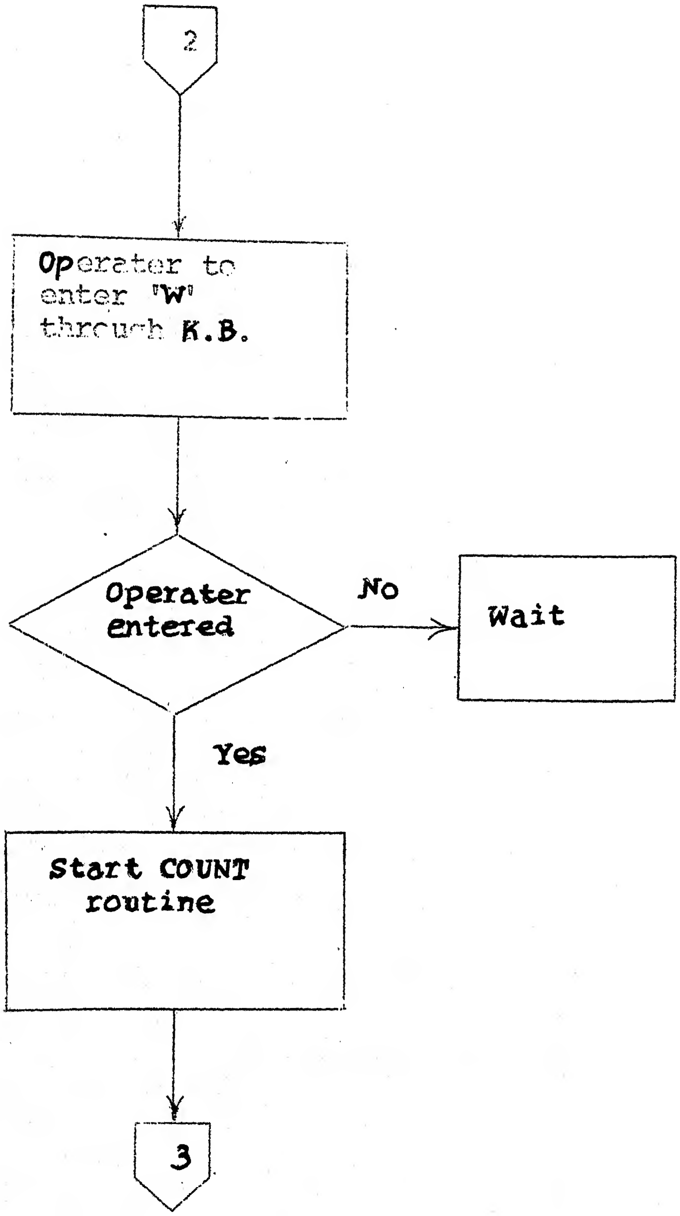
where I is integer value fed through datas switches.

APPENDIX V

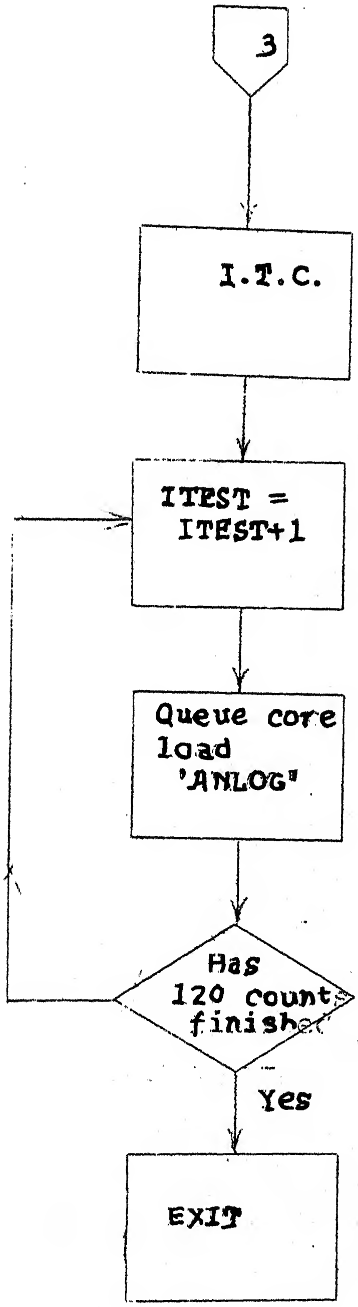


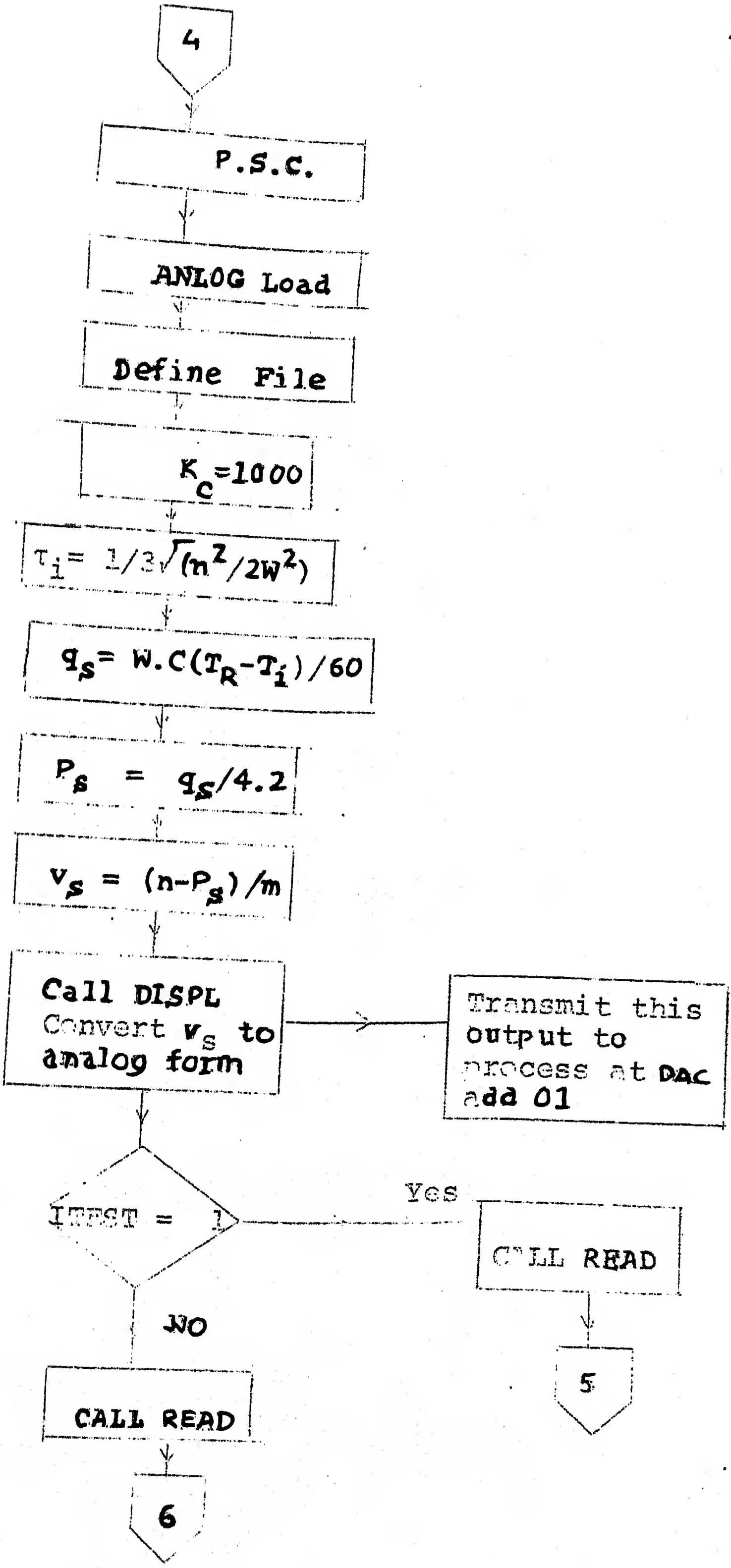
SERVICING ROUTINE FOR PISW BIT 3


1
P.S.C.
Load core load 'PMESS' and execute
Initialize counter
ITEST=1
Ask operater to ~~ex~~enter T_R through K.B.
Operater entered T_R
No
Wait
Ask operater to enter T_i through K.B.
Operater entered T_i
No
Wait
Yes
2

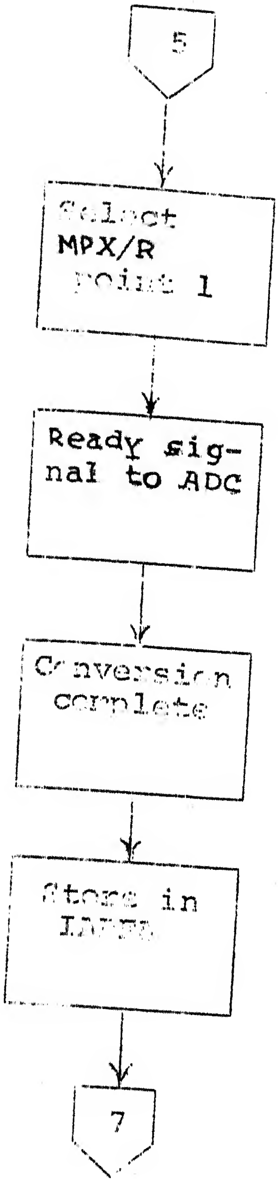


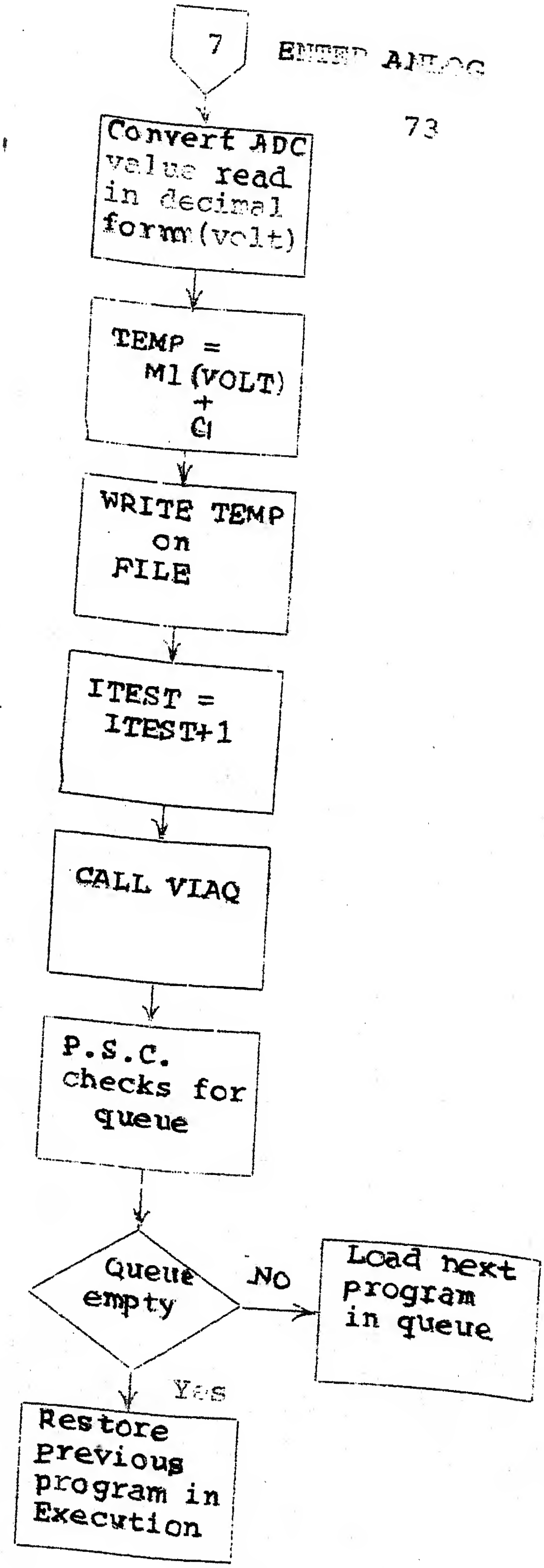
ROUTINE 'PMESS' PRINTS MESSAGE TO OPERATE

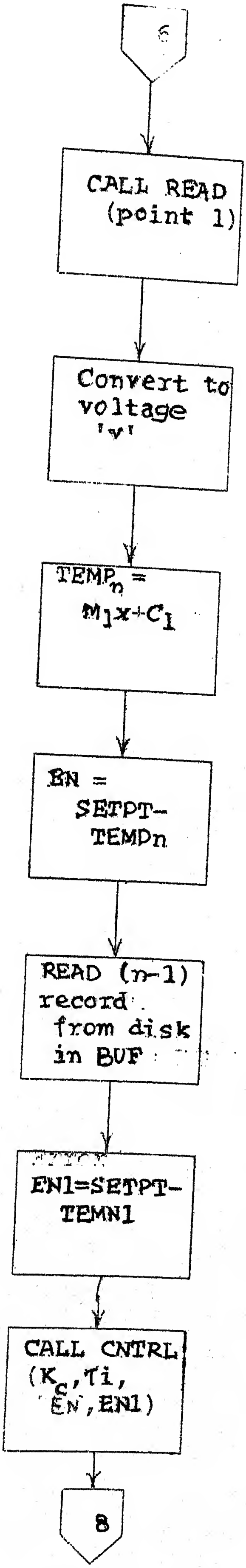

3
I.T.C.
ITEST =
ITEST+1
Queue core
load
'ANLOG'
Has
120 counts
finished
Yes
EXIT

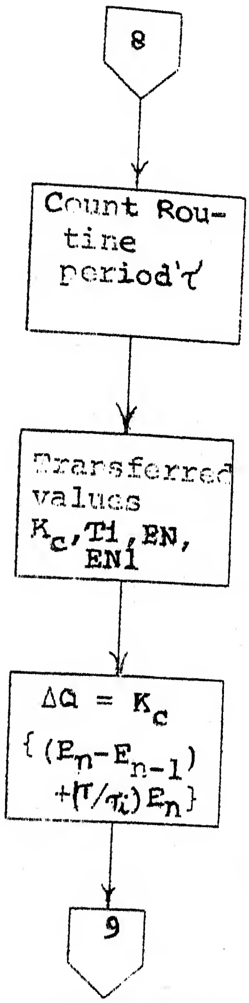


ANALOG ROUTINE


5
Select MPX/R point 1
Ready signal to ADC
Conversion complete
Store in
7

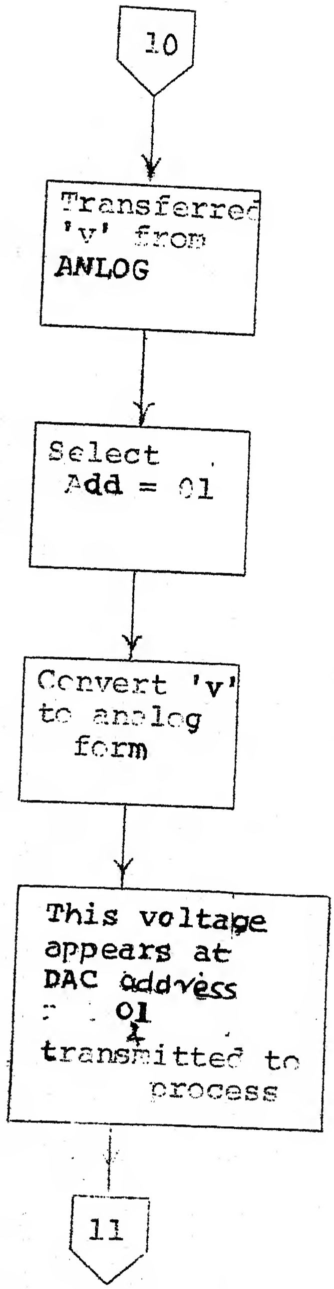

7
Convert ADC value read in decimal form(volt)
TEMP = M1(VOLT) + C1
WRITE TEMP on FILE
ITEST = ITEST+1
CALL VIAQ
P.S.C. checks for queue
Queue empty
NO
Load next program in queue
Yes
Restore previous program in Execution


6
CALL READ (point 1)
Convert to voltage 'v'
TEMPn = M1x+C1
EN = SETPT-TEMPn
READ (n-1) record from disk in BUF
EN1=SETPT-TEMN1
CALL CNTRL (Kc,τi, EN,EN1)
8

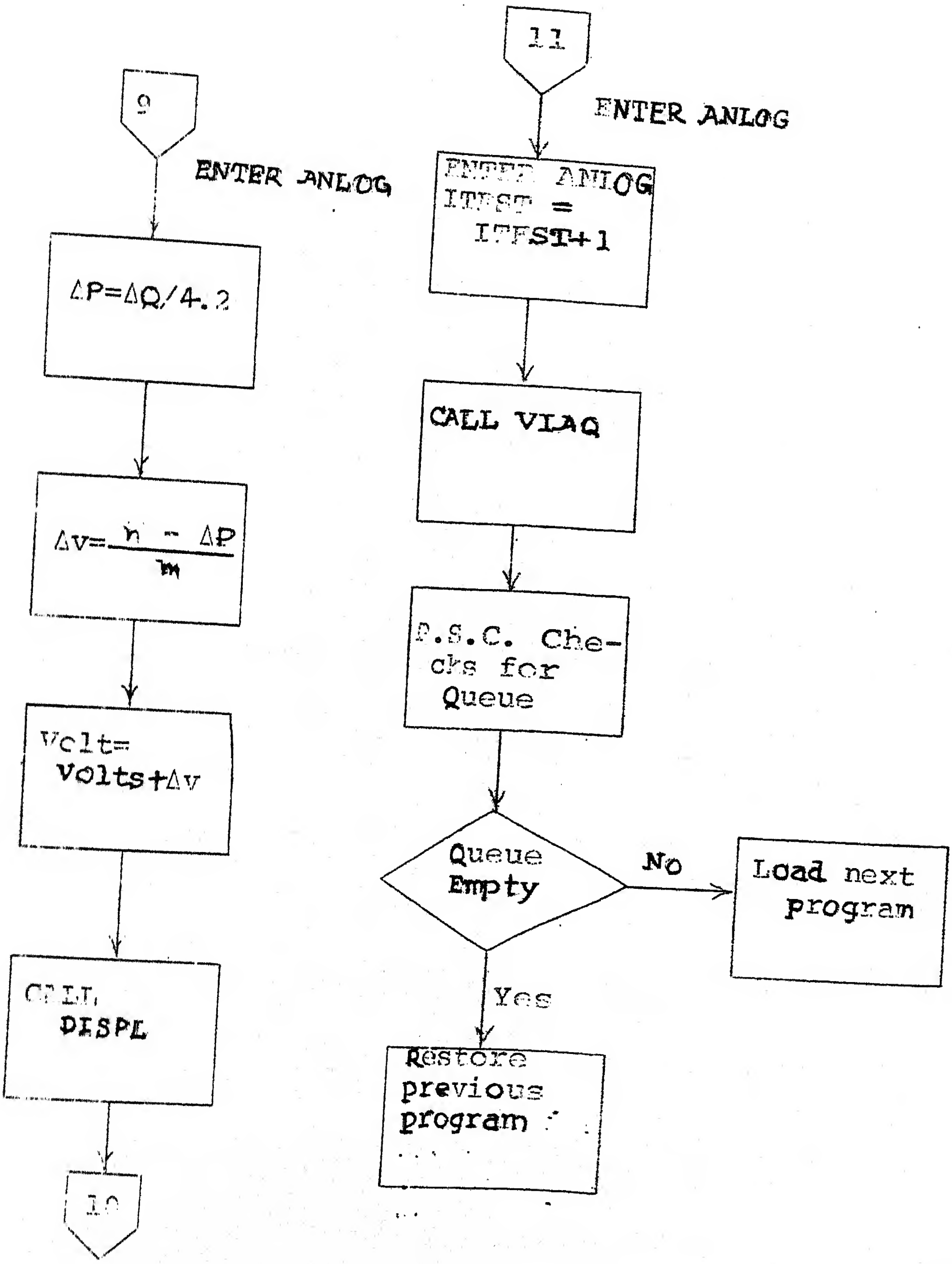


ENTER ANLOG

ROUTINE 'CNTRL'



ROUTINE DISPL


9
ENTER ANLOG
ΔP=ΔQ/4.2
Δv= h - ΔP / m
Volt= Volts+Δv
CALL DISPL
10
11
ENTER ANLOG
ENTER ANLOG ITEST = ITEST+1
CALL VIAQ
P.S.C. Checks for Queue
Queue Empty
No
Load next program
Yes
Restore previous program

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